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OMEGA LA REUNION ANTENNA SYSTEM: MODIFICATION AND VALIDATION TE--ETC(U)

JUL 79   J C HANSELMAN   N00123-78-C-0043

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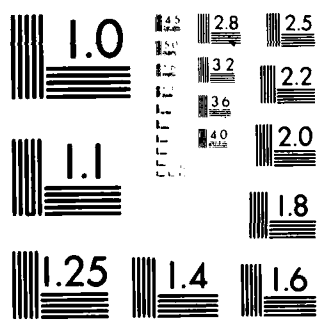

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Volume 1

OMEGA LA REUNION ANTENNA SYSTEM:
MODIFICATION AND VALIDATION TESTS

Volume 1: Report Proper

JC Hanselman, Megatek Corp.

10 July 1979

Final Report

Prepared for
US Coast Guard

Approved for public release; distribution unlimited

NAVAL OCEAN SYSTEMS CENTER
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ADMINISTRATIVE INFORMATION

Electronic measurements were performed on the La Reunion OMEGA Antenna System during the month of August 1978. The work was performed under NOSC project MP01538B10 with Megatek as contractor under NOSC Technical Agreement 532-008, Contract N00123-78-C-0043.

Volume 1 of NOSC TR 484 is the report proper. Volume 2 contains data sheets.

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- Omega vlf navigation system
- Antennas – configuration
- Monopole antenna
- Measurements – electrical
- Radiation resistance – efficiency

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Electronic measurements were performed on the La Reunion Omega Antenna System during the month of August 1978. The work was performed under NOSC project MP01538B10, with Megatek Corporation as contractor. The necessary connections to the antenna helix tuning coil were completed so that the station can now operate on 11.050 kHz. The total antenna system resistance was measured and found to compare favorably with original measurements made in 1975. An analysis was made of optimum gear ratios to use with the variometers used to keep the antenna system tuned. The electrical height of the antenna was found to be 163 metres for 10.2 kHz and to increase slightly with frequency to 170 metres at 13.6 kHz. The antenna system

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20. Abstract (Continued)

efficiency varies with frequency from 8% to 13.8%. The station can easily radiate the designed 10 kW power

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I. INTRODUCTION

1. The work described in this report was performed on the OMEGA La Reunion Antenna System by MEGATEK Corporation under Contract N00123-78-C-0043, NOSC Task Assignment 532-008. The scope of the task assignment includes completion of the installation of the 11.05 kHz helix tap, suitable testing to ensure operation on 10.2, 11-1/3, 13.6, 11.05 and 12.3 kHz and field intensity measurements (FIM) both airborne and on the surface to provide the radiated power output and benchmark calibration data.

2. The report is divided into two volumes. Volume 1 is the Technical Report proper and appendices in which measurement procedures are given. Volume 2 contains the recorded Data Sheets and calculations.

II. INSTALLATION OF THE FOURTH OMEGA FREQUENCY, 11.05 kHz

1. The helix tap for 11.05 kHz had previously been installed. The tap lead, however, had not been fabricated. One tap flange connector was installed, and the lead put in place. The cable was marked, lowered and the other flange connector installed. Many positions of the tap lead hanger were tried. None would prevent a sharp bend where the tap lead leaves the tap plate. This is the result of poor positioning of the 11.05 kHz tap plate. It appears to be one column too far clockwise (top view) around the helix. Due to potential interference, this required positioning the 12.3 kHz tap plate one column too far clockwise, also.

2. The tap lead for the 12.3 kHz frequency had previously been severely burned and removed. However, there was sufficient Litz cable on the station so a new tap lead was installed as follows. The length of the Litz cable was measured from the length of the original cable, which had the flanges cut off. Two flange sleeve lengths were added. The two flange connections were installed. When the cable was put in place, however, it was too short for normal installation. The probable cause was lack of knowledge about the amount of burned cable, external to the flanges, removed from the original length. Since the tap lead was too short, normal installation of the tap lead hanger was impossible. Therefore, sections of threaded permali were added to partially support the lead.

3. The f_{t2} tap plate was replaced by a splice. The tap plate was made ready for shipment to the Japan Omega station.

4. All of the necessary modification of the Timing and Control Set, to provide 11.05 kHz excitation to the transmitter, was done by the station personnel.

III. ANTENNA SYSTEM RESISTANCE (R_{as})

INTRODUCTION

1. It is necessary to know the total resistance of the antenna system (R_{as}) in order to:

   (a) correctly terminate the transmitter;

   (b) determine the maximum current permissible, as limited by the transmitter output capability; and

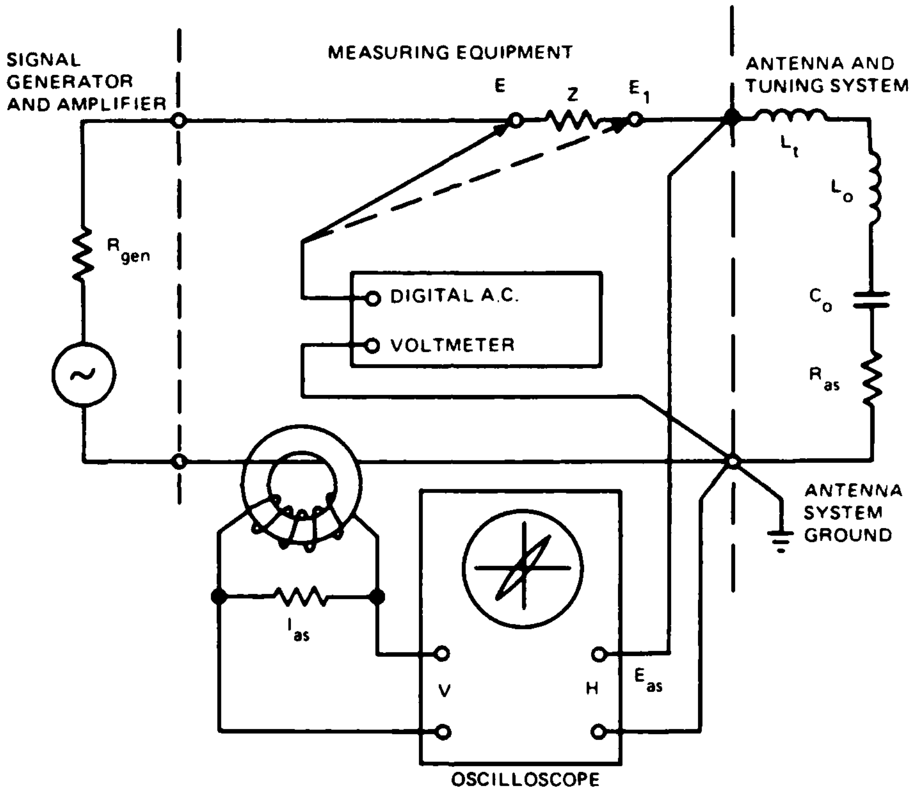
   (c) detect changes in the station efficiency.

PROCEDURE

1. The equipment required for this measurement, the schematic diagram of the instrumentation, and the step-by-step procedure are shown in figure 1. If a good non-inductive resistor is used for Z, it may not be necessary to include the value of inductance in the value of Z. It is normal to make several measurements, at different voltage levels, re-resonating the antenna system each time, to establish the values of E, E_1, and R_{as}. These data are recorded on Data Sheets 2 (DS-2).

RESULTS

1. The mean values of antenna system resistance, calculated for each frequency, are shown in figure 2 and table 1. Note that the first measurement of 12.30 kHz was higher than normal. This indicates a poor contact somewhere in the tuning system. The most likely candidate for the



1. Select Z approximately equal to R_{as} (estimated).
2. Set the generator to the frequency of measurement.
3. Tune the antenna to resonance as indicated by zero (0) degrees phase angle between I_{as} and E_{as}.
4. Adjust antenna current (I_{as}) to the maximum value allowable through Z.
5. Measure E and E_1.
6. Solve for: $\frac{E_1 Z}{E - E1} = R_{as}$

Figure 1. Incremental voltage method for antenna system resistance (R_{as}).

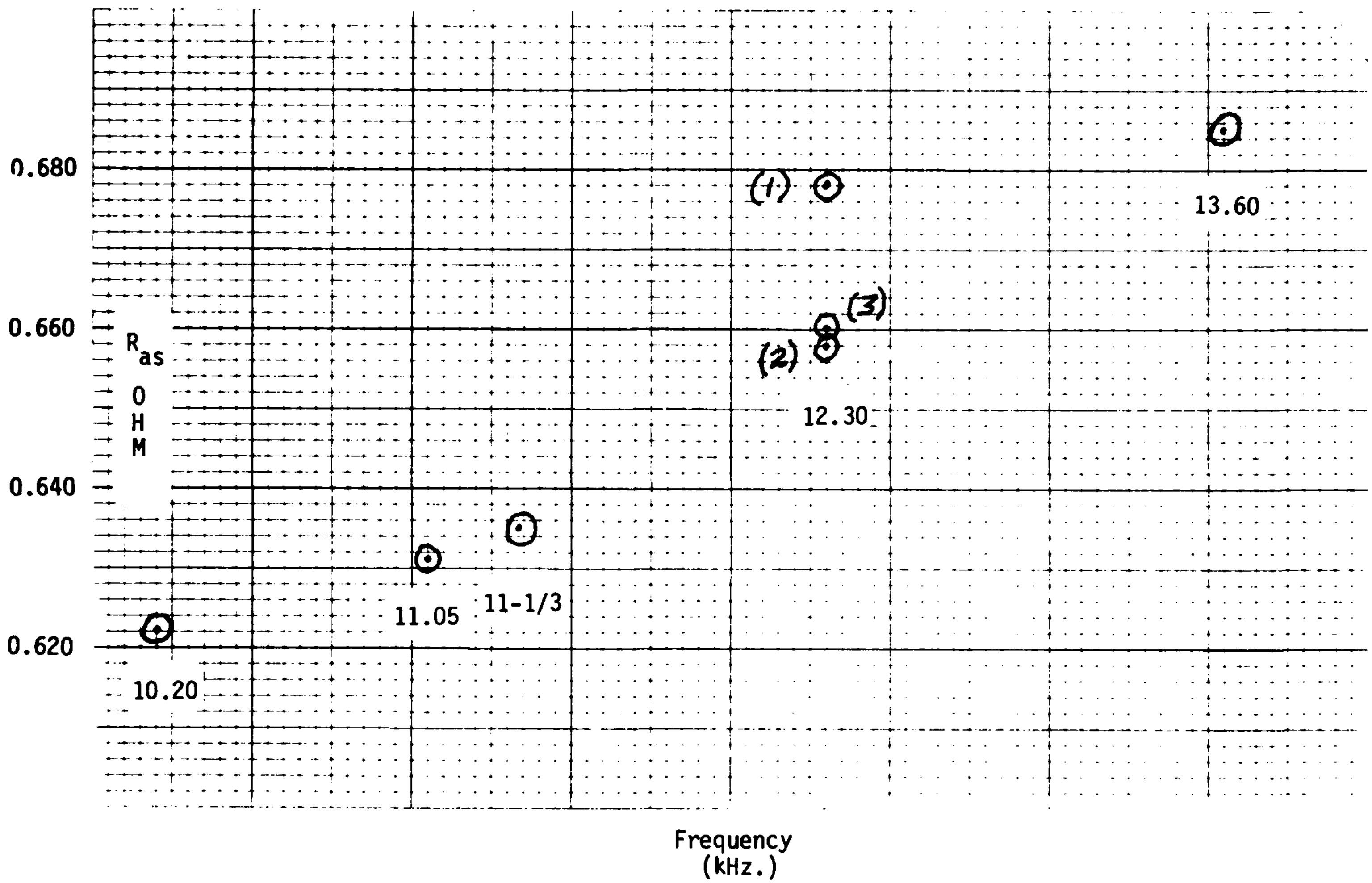


Figure 2. Antenna system resistance R_{as}.

TABLE 1. ANTENNA SYSTEM RESISTANCE.

Frequency (kHz)	Ras (Ohm)
10.20	0.622
11.05	0.631
11-1/3	0.635
12.30	(1) 0.678
	(2) 0.658
	(3) 0.660
13.60	0.685

Notes:

1. The first trial produced a value that did not fit the pattern of all other measurements and appeared too high.
2. Improvement noted after 5 minutes of cyclic operation.
3. Value obtained after a newly adjusted relay was installed.

fault is the antenna relay. Five minutes of keyed cyclic operation and then remeasurement showed marked improvement. In order to expedite the measurement, and subsequent return to normal operation, the antenna relay was replaced. Remeasurement showed a value that fit the curve established by measurement of the other frequencies.

2. These final measured values compared very favorably with the original measurements and conjecture made by Mr. B. Hagaman, of Kershner and Wright, in late 1975.

3. No change in the antenna impedance match was required.

IV. ANTENNA TUNING GEAR RATIO TESTS

INTRODUCTION

1. In order to design a gear box for the antenna tuning system and to specify preliminary gear ratios that would perform on a number of widely different antennas, it was necessary to assume that:

   (a) all capacitance of the antenna was lumped at the top;

   (b) all inductance was lumped in the tuning system; and

   (c) the variable inductance was linear with position over the entire range of movement.

None of these assumptions are true in a real installation. However, the approximation is close enough to provide a base for further refinement.

2. The original gear ratios were based on the ΔL required to retune a ΔC using the equation $f = (2\pi \sqrt{LC})^{-1}$. A further requirement was equal spacing of the ratios, about 1:1, which produced a ratio of 4/3 for 10.20 kHz and 3/4 for 13.60 kHz. This is a desirable concept to prevent absurd ratios but is not always possible with a discrete number of teeth on available sprockets.

3. It must be assumed that the self-inductance of the antenna will remain virtually constant when the structure is distorted by winds, and the variable causing a change in capacitance of the antenna can be

simulated by the addition of capacitance at the exit bushing of the helix house, or at the base insulator, the most accessible places.

TEST PROCEDURES

1. The procedures of Appendix F: REV. 1 were used, including the following notes:

(a) The capacitance spacing was 0.5 inch which produced a capacitance of approximately 1100 pF;

(b) Steps 3 through 11 were run two times giving four counter reading differences to be averaged.

2. The data obtained from the revolution counter for each frequency is recorded, and the mean values calculated, in tables 2 through 6. These tables follow the format of Data Sheet F1 REV. 1 shown in Appendix F.

3. Values of mean drive shaft revolutions (MDSR) from tables 2 through 6 and installed gear ratios were entered in table 7 and the indicated arithmetic operations completed. Note that table 7 follows the format of Data Sheet F2 REV. 1.

4. An inventory taken of all the sprockets available at the station is shown in table 8. From this list, all possible gear ratios were calculated and are shown in table 9.

TABLE 2. VALUES FOR MEAN DRIVE SHAFT REVOLUTIONS, 10.20 kHz.

Frequency (kHz)	ΔC (≈1100 pF)	Main Drive Shaft Counter Reading (Turns)	Drive Shaft Rotation (Turns)
10.20	OFF	170.90	
			21.20
	ON	192.10	
			21.20
	OFF	170.90	
			21.20
	ON	192.10	
			21.20
	OFF	170.90	
	Mean drive shaft revolutions (MDSR)		21.20

TABLE 3. VALUES FOR MEAN DRIVE SHAFT REVOLUTIONS, 11.05 kHz.

Frequency (kHz)	ΔC (≈1090 pF)	Main Drive Shaft Counter Reading (Turns)	Drive Shaft Rotation (Turns)
11.05	OFF	176.85	
			20.55
	ON	197.40	
			20.60
	OFF	176.80	
			20.60
	ON	197.40	
			20.60
	OFF	176.80	
	Mean drive shaft revolutions (MDSR)		20.59

TABLE 4. VALUES FOR MEAN DRIVE SHAFT REVOLUTIONS, 11 1/3 kHz.

Frequency (kHz)	ΔC (≈1100 pF)	Main Drive Shaft Counter Reading (Turns)	Drive Shaft Rotation (Turns)
11-1/3	OFF	175.00	
			19.30
	ON	194.30	
			19.40
	OFF	174.90	
			19.40
	ON	194.30	
			19.35
	OFF	174.95	
	Mean drive shaft revolutions (MDSR)		19.36

TABLE 5. VALUES FOR MEAN DRIVE SHAFT REVOLUTIONS, 12.30 kHz.

Frequency (kHz)	ΔC (≈1100 pF)	Main Drive Shaft Counter Reading (Turns)	Drive Shaft Rotation (Turns)
12.30	OFF	178.10	
			17.00
	ON	195.10	
			17.10
	OFF	178.00	
			17.10
	ON	195.10	
			17.10
	OFF	178.00	
	Mean drive shaft revolutions (MDSR)		17.08

TABLE 6. VALUES FOR MEAN DRIVE SHAFT REVOLUTIONS, 13.60 kHz.

Frequency (kHz)	ΔC (≅1100 pF)	Main Drive Shaft Counter Reading (Turns)	Drive Shaft Rotation (Turns)
13.60	OFF	173.15	
			15.80
	ON	188.95	
			15.85
	OFF	173.10	
			15.85
	ON	188.95	
			15.85
	OFF	173.10	
	Mean drive shaft revolutions (MDSR)		15.84

TABLE 7. PRELIMINARY GEAR RATIO CALCULATIONS.

Frequency (kHz.)	MDSR (Turns)		Installed Gear Ratio (2)		LSR (Turns) (2)		LSR Reference (1 & 2)		LSR Ratio (2)
10.20	21.20	X	1.33333 (48/36)	=	28.2666	÷	11.8800	=	2.37934
11.05	20.59	X	1.08000 (54/50)	=	22.2372	:	11.8800	=	1.87182
11-1/3	19.36	X	1.08000 (54/50)	=	20.9088	:	11.8800	=	1.76000
12.30	17.08	X	0.91667 (44/48)	=	15.6567	:	11.8800	=	1.31790
13.60	15.84	X	0.75000 (33/44)	=	11.8800	:	11.8800	=	1.00000

NOTES

(1) While any of the LSR values may be chosen, it is easier to use the value of 13.60 which will produce whole number ratios for the next step.

(2) Even though the precision of measurement does not warrant it, keep 6 significant figures to avoid rounding errors.

TABLE 8. INVENTORY OF SPROCKETS FROM SEVEN AVAILABLE GEAR BOXES.

Teeth (No.)	Quantity on Hand Per Box	Total	Required to Fill Installed Gear Boxes
33	1	7	4
36	3	21	
43	1	7	
44	2	14	4
45	1	7	
48	2	14	2
50	1	7	4
54	1	7	6*

* This indicates that the outside spare gear box can not be set up until it is known in which room the gear box is to be installed.

TABLE 9. AVAILABLE GEAR RATIOS.

Ratio	Sprockets Input-Output		Ratio	Sprockets Input-Output
0.61111	33-54		1.02273	45-44
0.66000	33-50		1.02326	44-43
0.66667	36-54		1.04167	50-48
0.68750	33-48		1.04651	45-43
0.72000	36-50		1.06667	48-45
0.73333	33-45		1.08000	54-50
0.75000	33-44		1.09091	36-33
0.75000	36-48		1.09091	48-44
0.76744	33-43		1.11111	50-45
0.79630	43-54		1.11628	48-43
0.80000	36-45		1.12500	54-48
0.81481	44-54		1.13636	50-44
0.81818	36-44		1.16279	50-43
0.83333	45-54		1.19444	43-36
0.83721	36-43		1.20000	54-45
0.86000	43-50		1.22222	44-36
0.88000	44-50		1.22727	54-44
0.88889	48-54		1.25000	45-36
0.89583	43-48		1.25581	54-43
0.90000	45-50		1.30303	43-33
0.91667	33-36		1.33333	44-33
0.91667	44-48		1.33333	48-36
0.92593	50-54		1.36364	45-33
0.93750	45-48		1.38889	50-36
0.95556	43-45		1.45455	48-33
0.96000	48-50		1.50000	54-36
0.97727	43-44		1.51515	50-33
0.97778	44-45		1.63636	54-33
1.00000	36-36	(Note 1)		

Note 1: Obviously any two gears with the same number of teeth will produce a ratio of 1.00000. Some of the larger gears may interfere with the idlers, so the original set of 36-36 is the only set shown.

5. As shown in table 10, only four sets of sprockets could be selected due to the limited range of sprocket sizes. Included at the bottom is the original set of sprockets showing the large peak-to-peak error.

RESULTS

1. The set of sprockets showing the lowest peak-to-peak error, in table 10, is selected for installation. The ratio and sprocket identification, for each frequency, is given in table 11.

2. Although nothing was done at the station to cause the variometers to change their normal operating position, the final variometer positions are included in table 12, and shown in figure 3, for the record.

RECOMMENDATIONS

1. Live with these values for a year, noting any problems in tracking that occur during the changing seasons.

2. After all the stations have been tested, it might be well to order new gears for all stations at one time.

TABLE 10. ERROR CALCULATIONS.

1. Required Gear Ratios.
2. Available Gear Ratios.
3. Peak-to-peak and individual errors.

Frequency (kHz)	13.60	12.30	11-1/3	11.05	10.20
LSR Ratio	1.00000	1.31818	1.76010	1.87202	2.37963
Required Ratio	0.61111	0.80555	1.07561	1.14403	1.45423
Available Ratio		0.81481	1.08000	1.13636	1.45455
Error (%)	1.82 p-p	+1.15	+0.41	-0.67	+0.02
Required Ratio	0.66000	0.87000	1.16167	1.23555	1.57056
Available Ratio		0.88000	1.16279	1.22727	1.51515
Error (%)	4.81 p-p	+1.15	+0.10	-0.67	-3.66
Required Ratio	0.66667	0.87879	1.17341	1.24804	1.58643
Available Ratio		0.88000	1.16279	1.25000	1.63636
Error (%)	4.06 p-p	+0.14	-0.91	+0.16	+3.15
Required Ratio	0.68750	0.90625	1.21007	1.28703	1.63600
Available Ratio		0.90000	1.20000	1.30303	1.63636
Error (%)	2.08 p-p	-0.69	-0.84	+1.24	+0.02
		As originally installed.			
Required Ratio	0.75000	0.98864	1.32008	1.40404	1.78472
Available Ratio		0.91667	1.08000	1.08000	1.33333
Error (%)	33.85 p-p	-7.85	-22.23	-30.00	-33.85

TABLE 11. SELECTED GEAR RATIOS.

	Frequency (kHz)				
	13.60	12.30	11-1/3	11.05	10.20
Ratio	0.61111	0.81481	1.08000	1.13636	1.45455
Sprockets (Input-Output)	33/54	44/54	54/50	50/44	48/33

Notes:

(1) Install these gear ratios with the sprockets near the rear of the variometer room.

(2) Make up a full set of sprockets in the spare variometer room. Use a set of 36/36 to fill the sixth space.

(3) The outside spare gear box cannot be made up in advance due to a shortage of 54 tooth sprockets.

TABLE 12. FINAL VARIOMETER POSITIONS.

Frequency (kHz)	Distance Inner Coil Down (inches)	(cm)
10.2	34-13/16	88.4
11.05	31-11/16	80.5
11-1/3	32-1/4	81.9
12.30	29-3/16	74.1
13.60	29-1/2	74.9

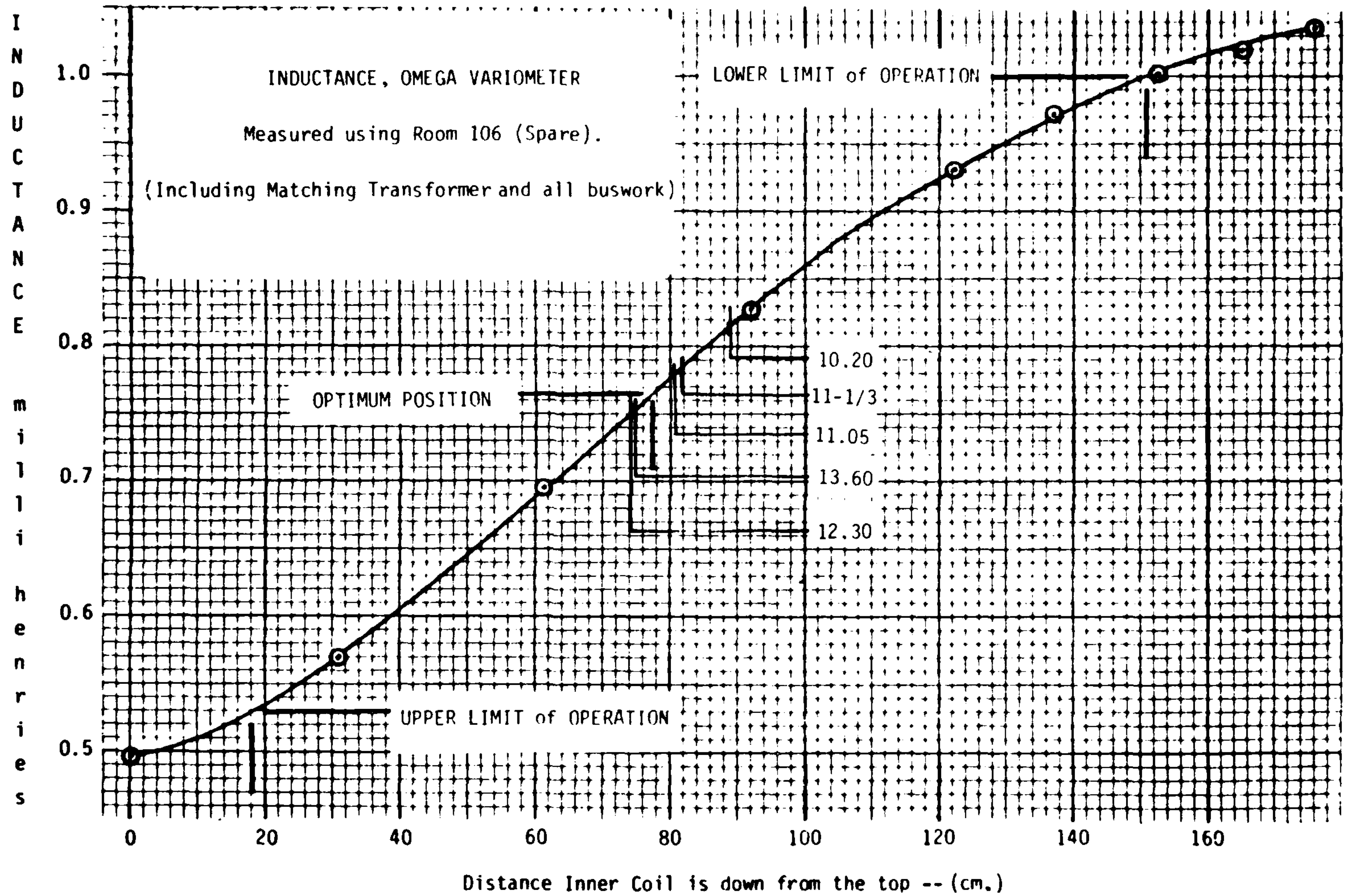


Figure 3. Final variometer positions.

V. FIELD INTENSITY MEASUREMENT

INTRODUCTION

1. To evaluate the performance of a station, the radiated power must be determined. Radiated power is determined by making field intensity measurements (FIM) in as many clear areas and in as many radial directions as possible. Clear areas means the absence of structures such as power lines, fences, metal towers, buildings, pipelines, etc., capable of modifying the field intensity being measured. Since there are other factors, including unseen or buried structures, geological inhomogeneities, etc., that will modify the field intensity, a great many measurements are desirable. Statistical methods are used to obtain the average values and to provide a means of identifying obviously erroneous values. Measurements such as these, taken on the Earth's surface require that the entire measurement area be reasonably flat and that the soil, over which propagation takes place, have rather high conductivity at the radio frequencies of interest.

2. Some of the OMEGA stations are located on sites which are almost impossible to measure on the ground. These are the mountainous coast of Norway, the mountainous island of Tsushima, Japan and the volcanic islands of Hawaii and La Reunion. These areas, in addition to being almost impassable, are characterized by poor and variable ground conductivity. These conditions dictate measurement sites remote from the poorly conducting ground plane and above the impassable terrain.

Some radial directions, at measurement distances, are over water. Surface (ship) measurements are not feasible because of the elaborate calibration that would be required. Due to the low duty cycle pulses of the OMEGA signals, a moving vehicle (fixed wing aircraft) is a very unattractive platform. The length of time required to obtain an accurate measurement requires a stationary platform. Above the terrain, this means a helicopter.

3. The radiated field-distance product normalized by the antenna current ($E_r d/I_a$), leads directly to the electrical height and radiation resistance of the antenna (see Appendix B). This number is convenient to use in statistical manipulation.

MEASUREMENTS

1. Antenna current was maintained at a constant level during the measurement periods using procedure B of Appendix D, Revision 1.

2. Field intensity measurements on the surface, for purposes of calibrating helicopters and benchmark sites, were made by the method of Appendix C. Airborne measurements were made by the method of Appendix E, Revision 1.

3. The locations of the land based measurement sites were first plotted on a map (scale 1:50,000) then converted to metric grid coordinates. These are shown in table 13. The location of the transmitting antenna and distances to the various land based sites are given in table 14.

TABLE 13. LAND BASED SITE LOCATIONS.

A. St. PIERRE (Map)

Metric Grid Scale: 5.505 inches = 7000 m.
0.7864 inch = 1000 m.

	Grid		Inches		
Site 1. (Benchmark)	44416 N	-	2.584	=	41130 N
	130562 E	+	3.911	=	135535
	139226 E	-	2.888	=	135554
			$\bar{X}$	=	135545 E
Site 2.	44416 N	+	2.660	=	47799
	49046 N	-	0.968	=	47815
			$\bar{X}$	=	47807 N
	130562 E	+	2.324	=	133517 E

B. St. DENIS (Map)

Metric Grid Scale: 5.500 inches = 7000 m.
0.7857 inch = 1000 m.

	Grid		Inches		
Site 3.	72144 N	+	4.011	=	77249
	81364 N	-	3.216	=	77270
			$\bar{X}$	=	77260 N
	147857 E	-	1.274	=	146236 E
Site 4.	72144 N	+	3.748	=	76914
	81364 N	-	3.502	=	76907
			$\bar{X}$	=	76911 N
	147857 E	+	2.461	=	150989
	156536 E	-	4.358	=	150989
			$\bar{X}$	=	150989 E

TABLE 13. (cont)

B. St. DENIS (Map) (cont)

	Grid		Inches		
Site 5.	72144 N	+	2.850	=	75771
	81364 N	-	4.394	=	75772
			$\bar{X}$	=	75772 N
	156536 E	-	0.152	=	156343 E
Site 8.	49040 N	+	2.409	=	52106
	53654 N	-	1.215	=	52108
			$\bar{X}$	=	52107 N
	130566 E	+	0.976	=	131808
	139216 E	-	5.818	=	131811
			$\bar{X}$	=	131810 E

C. St. BENOIT (Map)

Metric Grid Scale: 5.500 inches = 7000 m.
0.7857 inch = 1000 m.

	Grid		Inches		
Site 6.	72143 N	+	1.024	=	73446 N
	156538 E	+	3.906	=	161509
	165201 E	-	2.894	=	161518
			$\bar{X}$	=	161514 E
Site 7.	72143 N	+	3.963	=	77187
(Benchmark)	81366 N	-	2.282	=	77189
			$\bar{X}$	=	77188 N
	156538 E	+	1.209	=	158077
	165201 E	-	5.592	=	158084
			$\bar{X}$	=	158081 E

TABLE 13. (cont)

C. St. BENOIT (Map) (cont)

	Grid		Inches		
Site 10.	72143 N	+	2.795	=	75700
(Benchmark)	81366 N	-	4.443	=	75711
			$\overline{X}$	=	75706 N
	165201 E	+	0.978	=	166446
	173876 E	-	5.831	=	166455
			$\overline{X}$	=	166451 E

Site 9A (262°T and 17 meters from the monitor antenna)

	Metric Grid North	Metric Grid East
Monitor Antenna (From French Navy)	74372.72 N	158483.27 E
262°T, 17 meters	- 2.37	-16.83
Site 9A.	74370.35 N	158466.44 E

Notes: 1. Latitude and longitude lines were ruled on the maps. These were converted to metric grid lines and used as references from which distances to the various sites could be measured.

TABLE 14. DISTANCE AND AZIMUTH TRANSMITTING ANTENNA TO FI MEASUREMENT SITES.

Site	Grid (Metric)	Distance meters (km)	Azimuth Degrees True
Antenna*	66905 N 135200 E		
1	41130 N 135545 E	25,777 (25.8)	179.2
2	47807 N 133517 E	19,172 (19.2)	185.0
3	77260 N 146236 E	15,133 (15.1)	046.8
4	76911 N 150989 E	18,693 (18.7)	057.6
5	75772 N 156343 E	22,927 (22.9)	067.3
6	73446 N 161514 E	27,115 (27.1)	076.0
7	77188 N 158081 E	25,085 (25.1)	065.8
8	52107 N 131810 E	15,181 (15.2)	192.8
9A	74370 N 158466 E	24,434 (24.4)	072.2
10	75706 N 166451 E	32,467 (32.5)	074.3

* In accordance with precedent set during the FIM of Liberia, which has a similar antenna, the pull-off tower has been chosen as the center of the radiated field. The grid coordinates were scaled from site drawing No. 0,001,578. The official position of the supporting tower (1400 ft.) is given as:

67,145.50 N
135,295.50 E

4. The metric grid coordinates of the three radio distance measuring equipment (DME) transponder sites were provided by the French Navy. These are shown in Table 15.

5. The DME range parameters were calculated from the transmitting antenna and DME transponder grid coordinates using rectangular to polar conversion. These are shown in table 16.

6. Helicopter positioning over land was done visually. There were no suitable locations for DME transponders to cover the operating area. Visual positioning at low altitudes of 1000 feet is poor at best and, at the higher altitudes, up to 7000 feet, is highly inaccurate. Hovering was attempted over easily identified geographic locations and then converted to grid coordinates for computation of distance.

7. Helicopter positioning over water is done by DME using the method described in Appendix G.

8. Over water, it is necessary to have a reference location over which the pilot can hover. This prevents random drifting and ensures that the data is collected in essentially the same location. None of the usual visual markers (dye or smoke) were available so the French Navy supplied a radar equipped patrol vessel. The patrol vessel would stop at each measurement position to provide a visual hover reference.

9. The initial measurements taken over land are almost useless. All are, of necessity, taken over part of the "mountain." The first set of measurements, made using the helicopter of the Gendarmerie, was greatly

TABLE 15. DME TRANSPONDER LOCATIONS.

A. Primary (D1) Transponder

1. Pointe des Galets

72 622.28 N
134 988.09 E

2. Transponder antenna azimuth.

Radials A and B: 043° M.
Radials C and D: 258° M.

B. Secondary (D2) Transponder.

1. St. Suzanne

75 202.72 N
167 760.13 E

2. Transponder antenna azimuth.

Radials A and B: 324° M.

C. Secondary (D2) Transponder.

1. Pointe du Portail

38 912.76 N
135 682.28 E

2. Transponder antenna azimuth.

Radials C and D: 324° M.

TABLE 16. DME RANGE PARAMETERS.

Radials A and B

Site Number	Metric Grid North	Metric Grid East
D1 (Pt. des Galets)	72 622.28 N	134 988.09 E
D2 (St. Suzanne)	75 202.72 N	167 760.13 E
Station	66 905 N	135 200 E

D1 to D2:	Az.	8.549 787 232 EX1	°T.
	Dist.	3.287 347 376 EX4	m.
Station to D1:	Az.	3.578 773 135 EX2	°T.
	Dist.	5.721 205 856 EX3	m.

Radials C and D

Site Number	Metric Grid North	Metric Grid East
D1 (Pt. des Galets)	72 622.28 N	134 988.09 E
D2 (Pt. du Portail)	38 912.76 N	135 682.28 E
Station	66 905 N	135 200 E

D1 to D2:	Az.	1.788 202 580 EX2	°T.
	Dist.	3.371 666 708 EX4	m.
Station to D1:	Az.	3.578 773 135 EX2	°T.
	Dist.	5.721 205 856 EX3	m.

Notes:

1. The values of azimuth and distance are given to ten significant figures only to minimize errors in the computational process.
2. The notation "EX(N)" means the exponent of 10. This form is used because of the keyboard of the calculator used.

reduced in value when it was discovered that the antenna current was not being measured properly. They were discarded and plans made to use the civilian helicopter over land after the overwater measurements were completed.

10. The civilian helicopter, operated by Reunion Air Service (RAS) was equipped with floats for overwater operations. It was taken to Site 1 and calibrated in accordance with Appendix E, Revision 1. (Land based site locations are given in table 13.) The calibration summary is given in table 17. At the end of calibration flight it was discovered that again the antenna current was being measured wrong. Due to limited helicopter time available, the calibration flight could not be repeated. It had to be assumed that any changes during the calibration measurements would be minor. It was verbally confirmed that no adjustments had been made during the period of the flights; therefore, the calibration is valid but the tripod measurements could not be used for benchmark data.

11. The original plan was to fly four over-water radials, each with five hover stops at 20 through 40 km from the station. Due to the high noise level of the helicopter, the plan was changed to five stops at distances of 15 through 35 km. Because of the language problem in the helicopter and the length of time required for the patrol vessel to reposition itself, the plan was shortened to four stops at 15 through 30 km. Due to equipment failures, and the lack of contingency time in the helicopter contract only two four-stop radials and one three-stop radial were flown over water (see figure 4). A summary of the over water flights is given in table 18.

TABLE 17. CALIBRATION SUMMARY. (HELICOPTER WITH FLOATS)

		Field Intensity (E_g, mV.)		
		Tripod*	Helicopter	
Frequency (kHz)			Loop toward the station	Loop away from the station
10.20		24.5	23.6	24.0
		24.4	24.0	24.1
		24.4	24.1	24.0
	$\bar{X}$	24.43	23.90	24.03
		K_3	1.02	1.02
11.05		26.3	26.1	26.6
		26.3	25.7	26.4
		26.3	26.1	26.8
	$\bar{X}$	26.30	25.97	26.60
		K_3	1.01	0.99
11-1/3		26.7	26.4	27.3
		26.7	26.6	26.8
		26.7	26.9	27.2
	$\bar{X}$	26.70	26.63	27.10
		K_3	1.00	0.99
12.30		29.8	29.9	30.3
		29.7	29.6	30.1
		29.8	30.1	30.1
	$\bar{X}$	29.77	29.87	30.17
		K_3	1.00	0.99
13.60		33.4	33.4	33.1
		33.2	32.9	33.0
		33.3	33.3	33.5
	$\bar{X}$	33.30	33.20	33.20
		K_3	1.00	1.00
		$\bar{X}$ (K_3)	1.01	1.00

*These "tripod" data are not used for benchmark data (see text).

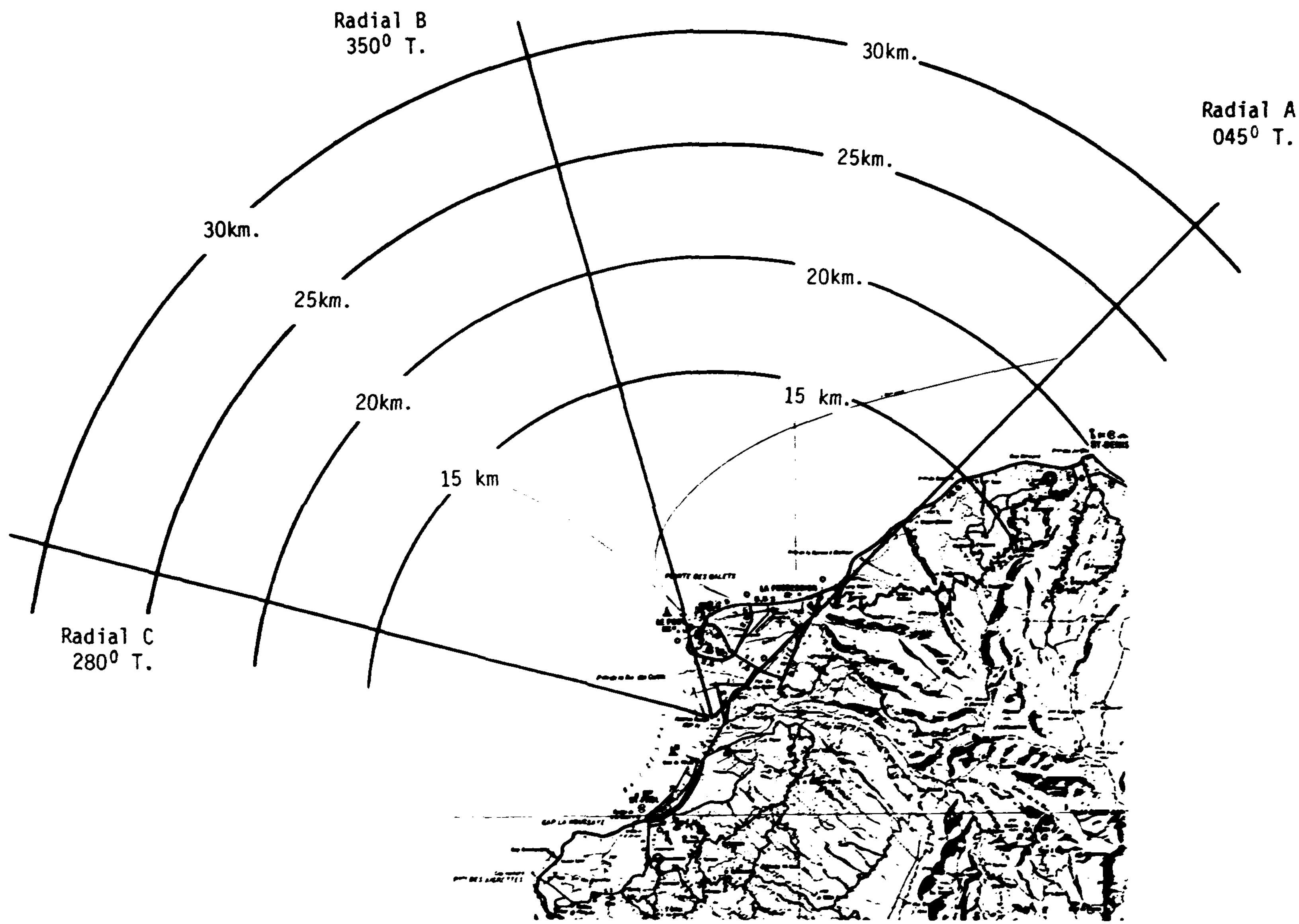


Figure 4. Over water radials.

TABLE 18. OVER WATER MEASUREMENTS - SUMMARY.

Frequency (kHz)	Number of Measurements	Mean Value of $E_r d/I_a$	Standard Deviation	h_e (meters)	h_e (feet)	R_r (Ohm)
		Radial A, 045°T. (Partly over water)				
10.20	8	1.926	0.059	150	493	0.0412
11.05	8	2.037	0.041	147	481	0.0461
11-1/3	8	2.088	0.037	147	481	0.0484
12.30	8	2.366	0.078	153	502	0.0622
13.60	8	2.544	0.049	149	488	0.0719
		Radial B, 350°T. (Mostly over water)				
10.20	9	2.085	0.022	163	534	0.0483
11.05	9	2.251	0.035	162	532	0.0563
11-1/3	9	2.322	0.032	163	535	0.0599
12.30	9	2.598	0.027	168	551	0.0750
13.60	9	2.896	0.034	169	556	0.0932
		Radial C, 280°T. (Mostly over water)				
10.20	6	2.094	0.017	163	536	0.0487
11.05	6	2.278	0.039	164	538	0.0577
11-1/3	6	2.335	0.025	164	538	0.0606
12.30	6	2.592	0.022	168	550	0.0746
13.60	6	2.937	0.059	172	564	0.0958
		Radials A, B and C				
10.20	23	2.030	0.089	158	520	0.0458
11.05	23	2.184	0.116	157	516	0.0530
11-1/3	23	2.244	0.121	158	517	0.0560
12.30	23	2.516	0.122	163	534	0.0703
13.60	23	2.788	0.181	163	535	0.0864

12. After the over water measurements were completed a new contract was awarded for over land measurements. The equipment was reinstalled in the helicopter, which had been reconfigured to landing skids, and calibration measurements were made again at Site 1. Table 19 contains the calibration summary.

TABLE 19. CALIBRATION SUMMARY.
(Helicopter with normal landing skids.)

		Field Intensity (E_g, mV.)		
		Tripod	Helicopter	
Frequency (kHz)			Loop toward the station	Loop away from the station
10.20		24.6	24.6	24.6
		24.6	24.9	24.2
	$\overline{X}$	24.60	24.75	24.40
		K_3	0.99	1.01
11.05		26.8	26.7	27.0
		26.7	27.0	26.9
	$\overline{X}$	26.75	26.85	26.95
		K_3	1.00	0.99
11-1/3		27.1	26.6	27.5
		27.1	27.2	27.4
	$\overline{X}$	27.10	26.90	27.45
		K_3	1.01	0.99
12.30		30.2	30.1	30.1
		30.3	30.4	29.7
	$\overline{X}$	30.25	30.25	29.90
		K_3	1.00	1.01
13.60		34.0	34.0	34.6
		33.9	34.0	34.2
	$\overline{X}$	33.95	34.00	34.40
		K_3	1.00	0.99
		$\overline{X}$ (K_3)	1.00	1.00

13. Since the antenna current was being measured correctly, the tripod data is acceptable as benchmark data.

14. Immediately following the calibration flights, a height-gain series of flights were begun. Measurements were made at altitudes of 1000, 2000, 3000, and 4000 feet above the surface before returning to the base for fuel.

15. After a quick analysis of the data, it was decided to go higher over Site 1 since the signal was still rising with altitude.

16. After trying three times at three sites to get above three thousand (3000) feet, and failing because of high winds, the flight was aborted due to a clogged fuel filter and no spare available.

17. On Sunday morning, 20 August 1978, height-gain flights were resumed over Site 1. Altitudes of 5000, 6000 and 7000 feet above the surface were obtained before high winds limited the altitude. A graph of these measurements is shown in figure 5. Immediately following the measurements over Site 1, measurements were made over Sites 2 and 8 before returning to the station for fuel. After a quick fuel stop, measurements were made at Sites 3, 4 and 5.

18. This concluded all measurements by helicopter.

DISCUSSION

1. Airborne measurements were made at varying distances over five radial directions from the transmitting antenna. Two of these (B and C) were predominantly over water, one (A) was partly over water (see figure 4) and two (South and Northeast) were completely over land. Due to previous

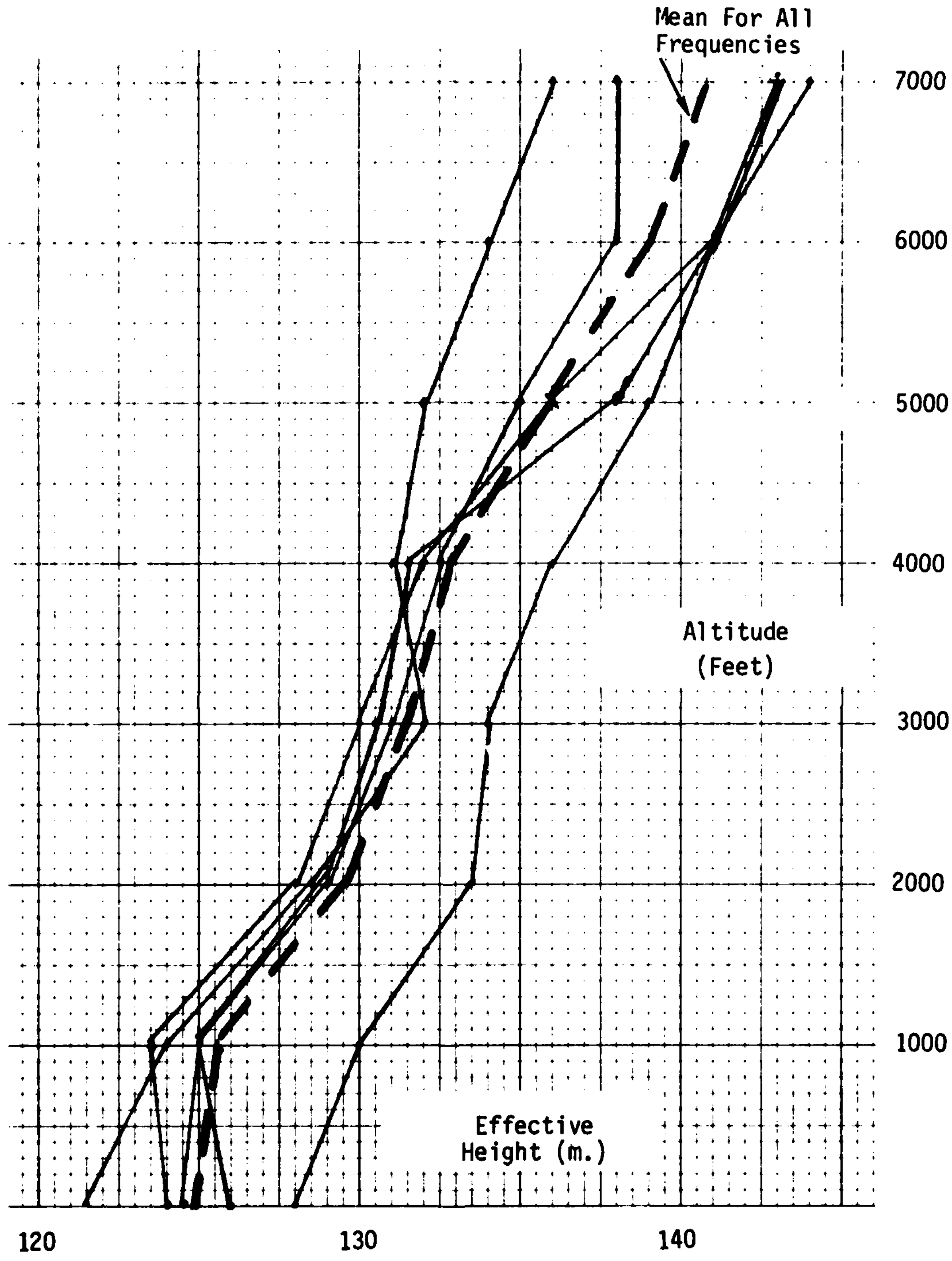


Figure 5. Height gain, Site 1.

experience, and the high cost of helicopter flight time for extensive testing, the over water flights were made at an altitude of 1000 feet. Calculation of radiation characteristics, based on these measurements, showed very good correlation for radials B and C. Good correlation was apparent with radial A when compared to radials B and C. A bar graph of calculated effective heights at several distances for each radial is shown in figure 6. Ground based and over land measurements flown as high as possible produced data of poor correlation to the over water radials. Height-gain measurements, previously shown as figure 5, seem to indicate that the over land measurements were still under the influence of the large central mountain complex of La Reunion. Over land measurements cannot be made without interference from the mountain. The dashed line of figure 5 is the mean value of the effective height calculated from data taken over Site 1 at the altitudes indicated. Other over land measurements were made on all frequencies at an altitude of 7000 feet. A bar graph of calculated effective heights at several distances for these measurements is shown in figure 7.

2. Measurements taken over radial paths consisting almost completely of sea water will produce almost constant values of normalized field-distance products. Measurements taken over land, which has low conductivity, may be used provided the vehicle can fly high enough to escape the attenuation near the surface. In this case, the practical limit of height was reached before the field reached its highest value.

3. Since the two radials (B and C), which were totally over water, produced the most uniform normalized field-distance products, these measurements were taken as the true values. The one radial (A) which was

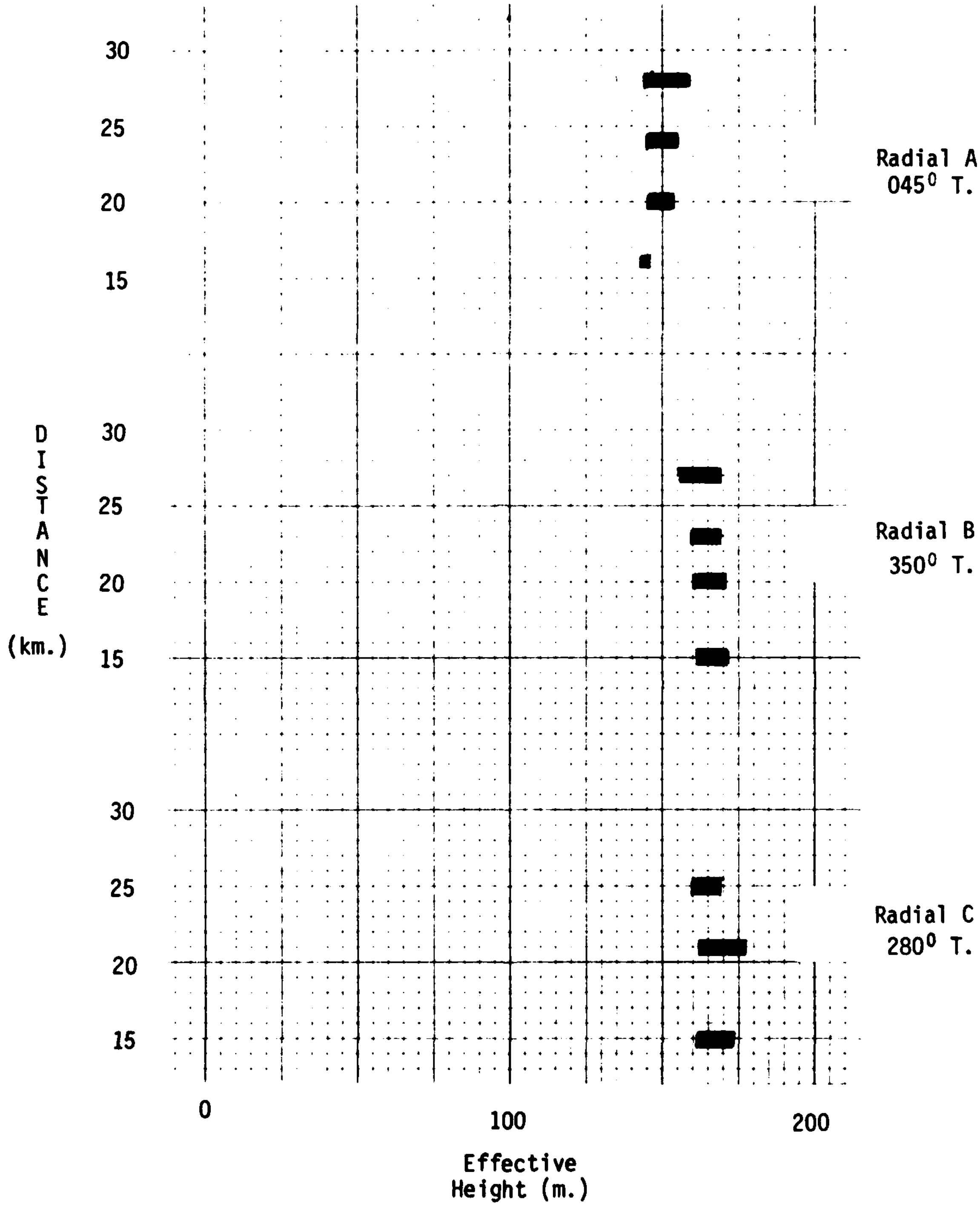


Figure 6. Over water measurements.

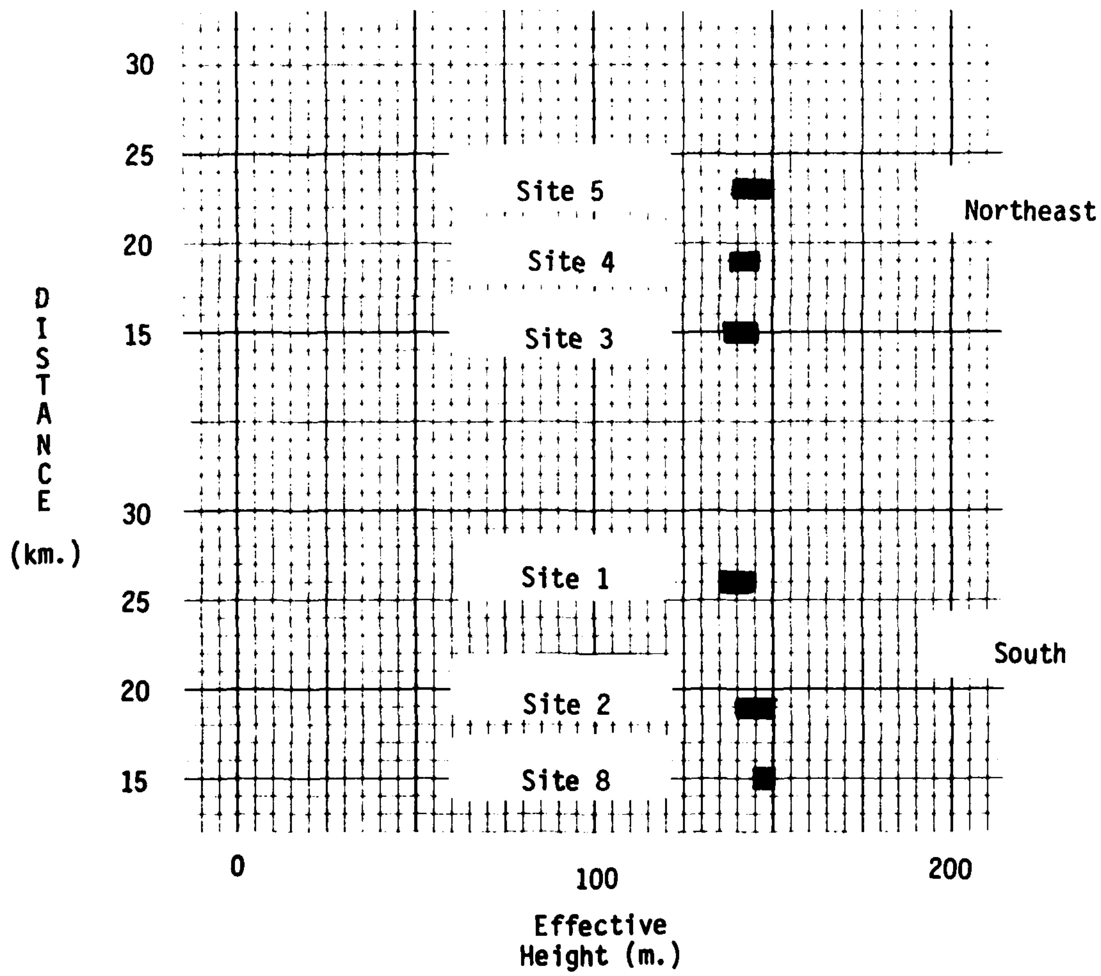


Figure 7. Over land measurements made at 7000 foot altitude.

approximately half over land and half over water produced measurements near the over water values. Had time permitted, it would have been interesting to perform height-gain measurements on this radial. The over land measurements were not considered when calculating the antenna characteristics.

RESULTS

1. A summary of the field intensity measurements taken on radials B and C, with the calculated antenna parameters, is given in table 20.

2. Station operating parameters, based on the calculated antenna characteristics, are given in table 21.

TABLE 20. FIELD INTENSITY-SUMMARY.

Frequency (kHz)	Number of Measurements	Mean Value of $E_r d/I_a$	Standard Deviation	h_e (meters)	h_e (feet)	R_r (Ohm)
10.20	15	2.098	0.020	163	535	0.0485
11.05	15	2.262	0.038	163	534	0.0569
11-1/3	15	2.327	0.029	163	536	0.0602
12.30	15	2.595	0.024	168	551	0.0748
13.60	15	2.912	0.048	170	559	0.0942

TABLE 21. STATION OPERATING PARAMETERS - ANTENNA.

Frequency (kHz)	R_r (Ohm)	I_a (10 kW) (amps)	I_{as} (I_a/0.98) (amps)	R_{as} (Ohm)	I_{as} (Max) (amps)	P_r (Max) (kW)
10.20	0.0485	454	463	0.622	491	11.2
11.05	0.0569	419	428	0.631	488	13.0
11-1/3	0.0602	408	416	0.635	486	13.7
12.30	0.0748	366	373	0.660	477	16.3
13.60	0.0942	326	332	0.685	468	19.8

3. The graph of effective height versus frequency of the La Reunion antenna is shown in figure 8. The graph of the Liberia antenna, which is almost identical, is also included as a matter of interest.

CONCLUSIONS

1. As indicated in table 21, OMEGA La Reunion will easily radiate the nominal power of 10 kW on all frequencies.

2. There is no reason to believe that the field intensity is asymmetrical at large distances, but within the constraint of 1 to 2 wavelengths distance this is impossible to prove.

3. The performance of the antenna system appears to be superior to the antenna of OMEGA Liberia. While the two antennas are essentially identical above ground, the radial ground system of the Reunion antenna has 2.7 times the area of the Liberian radial ground system. It is centered approximately

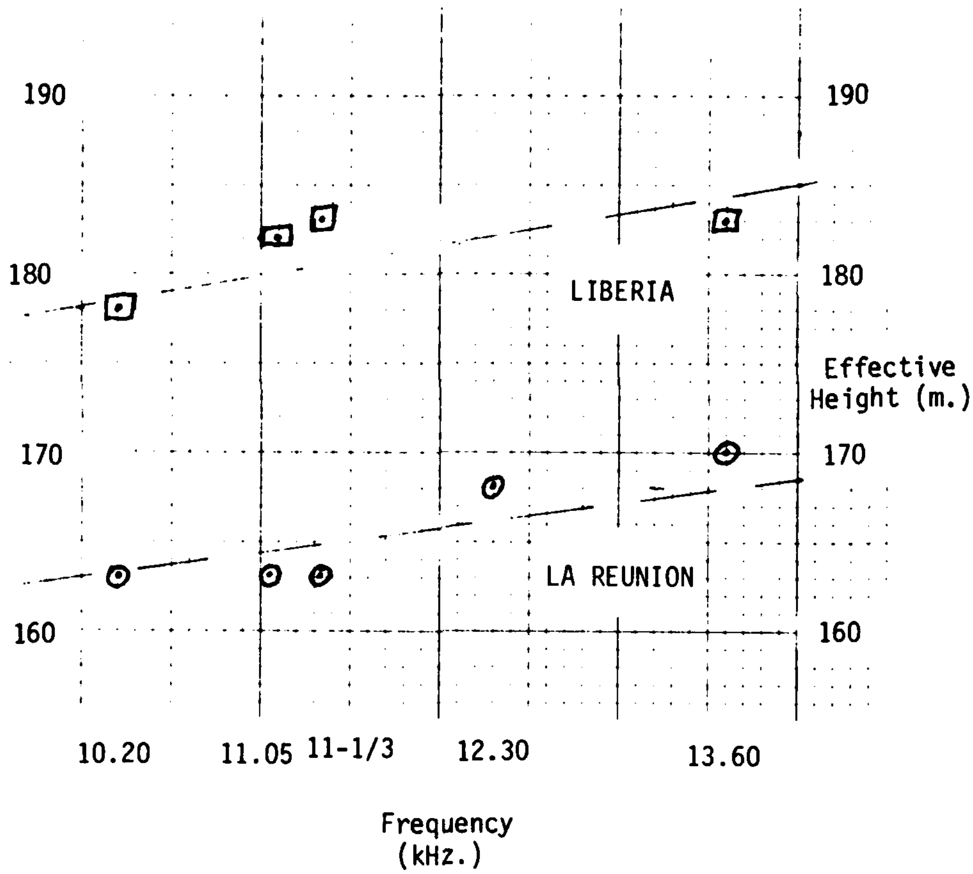


Figure 8. Antenna effective height.

midway between the helix house and the tower and collects ground return currents from all areas immediately under the active top radials. In contrast the smaller radial ground system of the Liberian antenna system is centered around the helix house and appears to directly collect ground return currents from only about one-fourth (1/4) of the area under the active top radials.

VI. BENCHMARK

LOCATIONS

1. To make field intensity measurements in the future, for determination of any changes in the antenna system, it is required that one or more benchmark sites be chosen for these measurements. For meaningful comparisons, the local environment of a chosen site should not change. The ideal procedure is to select a site, or sites, under the control of the operating agency. In this case, the only site under control of the operating agency was the monitor site. This site is located in an extensive antenna field, near large microwave antennas and is in an active sugar cane field. The author was told, by the French technician, that the monitor antenna ground system consisted of only four buried radials. Since the location is in an active sugar cane field, the ground radials may be subject to damage during soil preparation. Since the monitor site was not acceptable, three other sites were selected. These are sites 1, 7 and 10. The locations of these sites are shown in table 22 in terms of the metric grid and description. Map locations are shown as figures 9, 10 and 11.

MEASUREMENTS

1. Field intensity measurements were made at Site 7 on 16 August 1978, Site 1 on 18 August 1978 and Site 10 on 22 August 1978. The OMEGA station technician was instructed in the procedures and participated in the measurements, taking five sets of readings without assistance.

TABLE 22. BENCHMARK LOCATIONS.

Site	Map and Metric Grid	Description
1	St. Pierre 41,130 N 135,545 E	On an abandoned airstrip, south of St. Leu. The map, a section of which is reproduced as Figure 9, shows a fork in the road which goes down the hill from the main road. The right hand road of the fork doesn't exist. The exact site is the center of the runway at the intersection of the left hand fork of the access road.
7	St. Benoit 77,188 N 158,081 E	Continue past the end of the road, which parallels the runway of Gillot Airport, following a two track road (trail). After passing some old bridges there is a knoll on the right which overlooks both the beach and the road. The exact site is on that knoll. A section of the map is shown as Figure 10. This is the least desirable of the three sites.
10	St. Benoit 75,706 N 166,451 E	North of the main road at Pointe des Haziers. Go to the end of the access road where it intersects a perimeter road in a cane field. The exact site is 2 meters north of the road intersection. A section of the map is shown as Figure 11. This is probably the best site of the three since the site ratio (K_3) is the lowest.

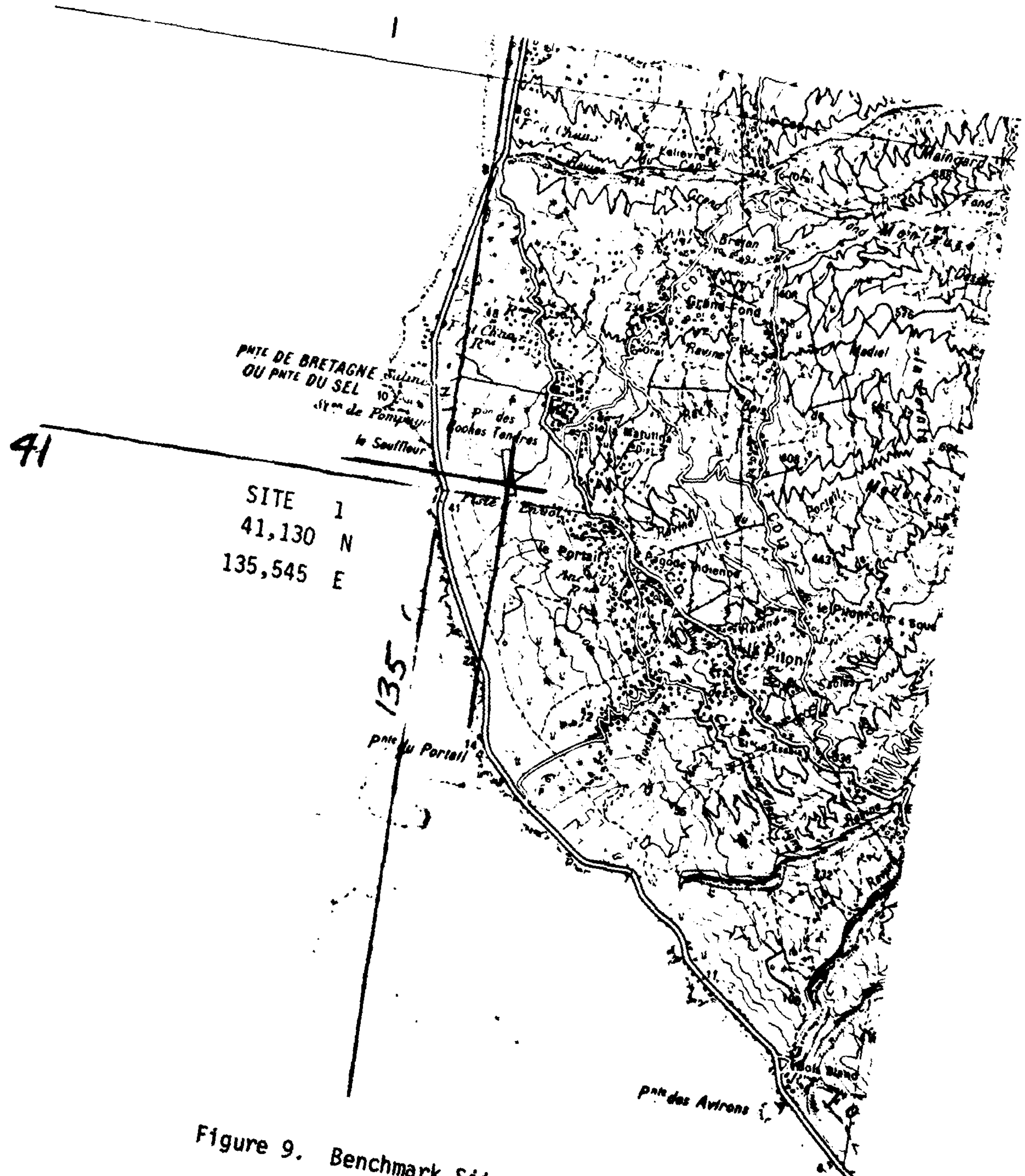


Figure 9. Benchmark Site 1.

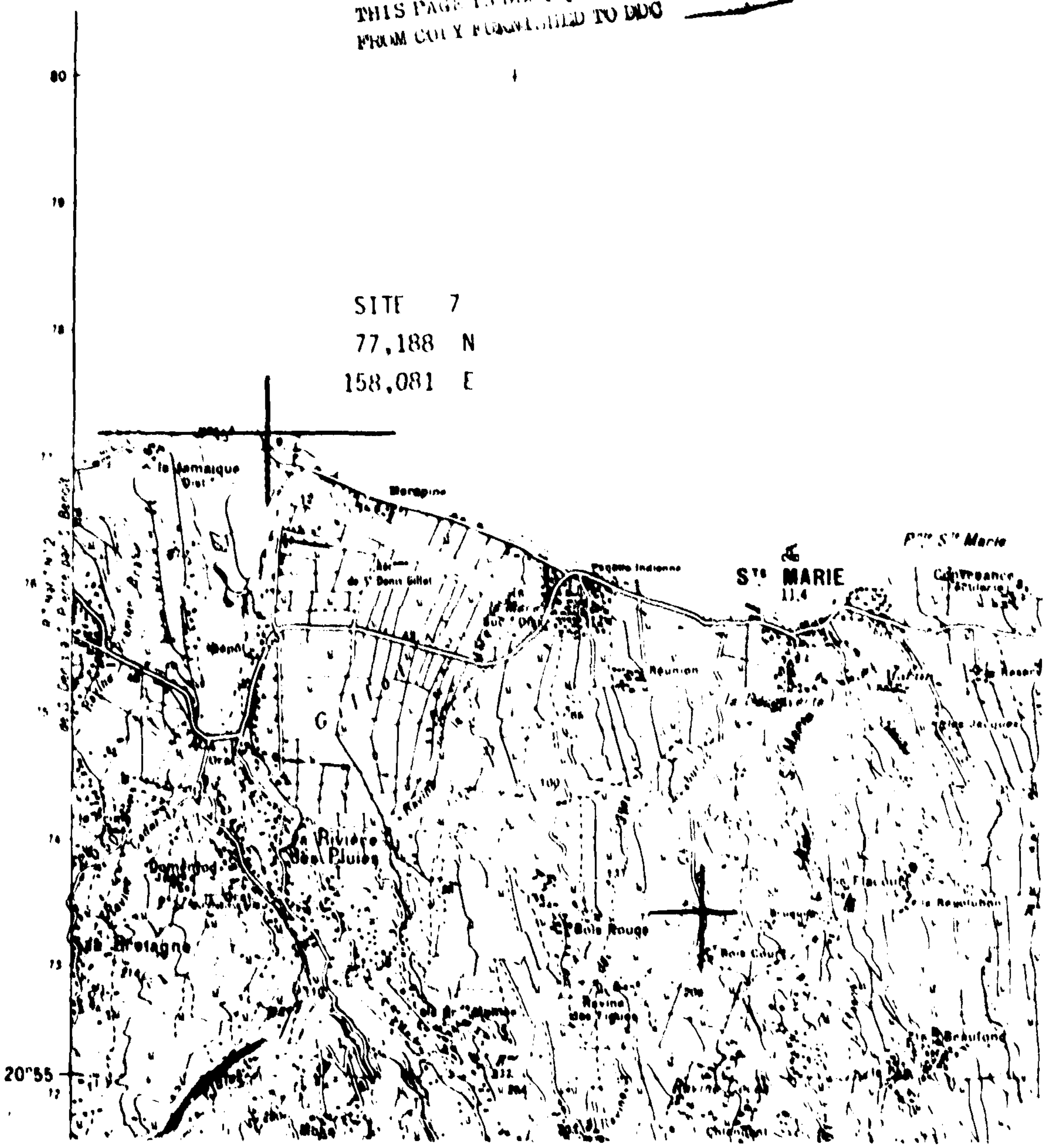


Figure 10. Benchmark Site 7.

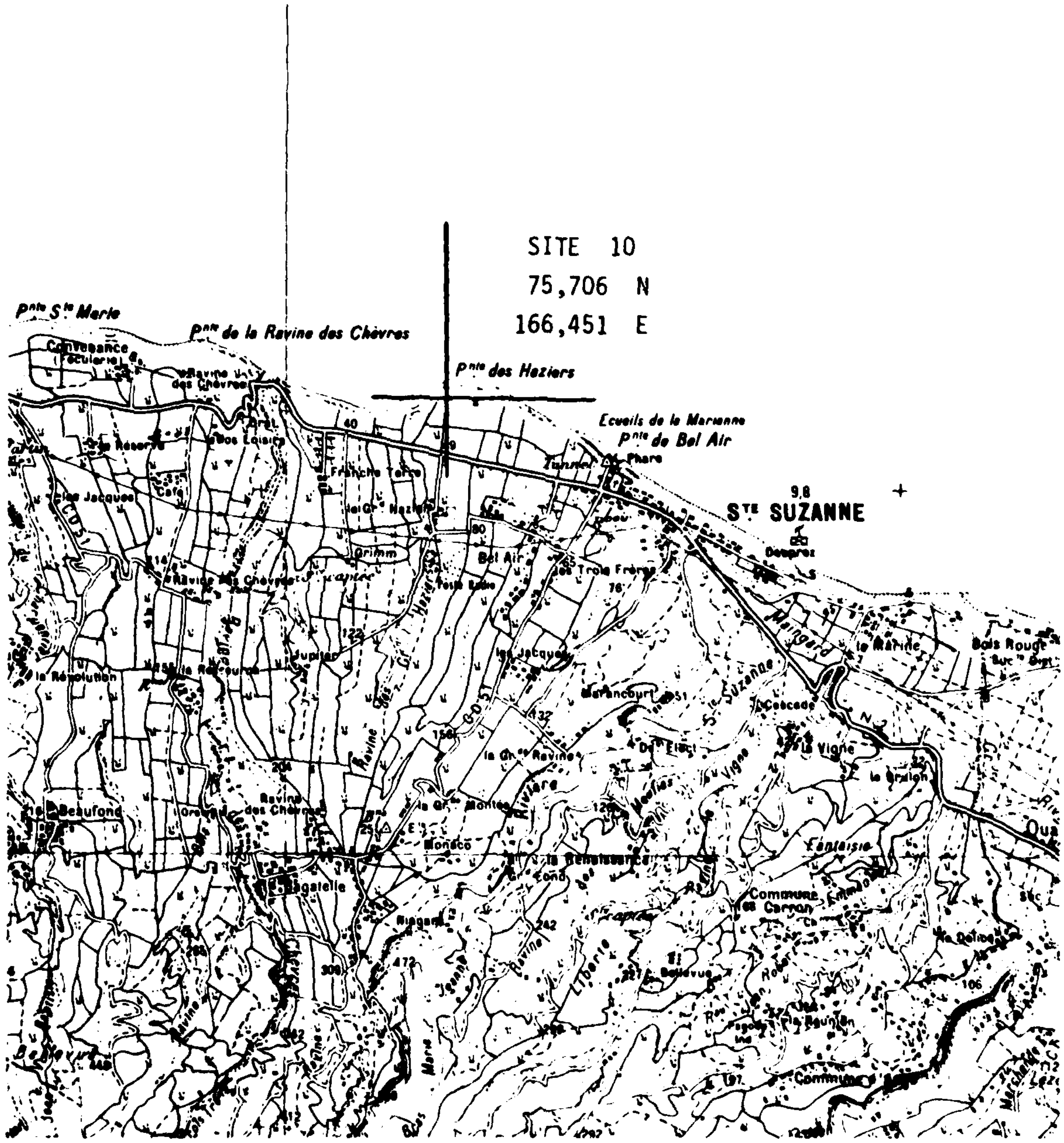


Figure 11. Benchmark Site 10.

2. From data taken at each site, the normalized field-distance product ($E_e d/I_a$) was calculated for each measurement of each frequency. The mean value of $E_r d/I_a$ was calculated for each frequency at each site. The summary values of $E_r d/I_a$, taken from table 20, divided by the mean values calculated becomes the "Site Ratio" and may be called K_3 in calculations of radiated field, radiated power, etc. These calculations and ratios are given for each site in tables 23, 24 and 25.

TABLE 23. BENCHMARK RATIO - SITE 1.

Frequency (kHz)	$E_r d/I_a$ (Summary)	÷	$E_r d/I_a$ (Mean)	=	Ratio (K_3)
10.20	2.089		1.592		1.312
11.05	2.262		1.751		1.292
11-1/3	2.327		1.769		1.315
12.30	2.595		1.949		1.331
13.60	2.912		2.244		1.298
	Mean Ratio				1.31
	Standard Deviation				0.015

TABLE 24. BENCHMARK RATIO - SITE 7.

Frequency (kHz)	E_rd/I_a (Summary)	÷	E_rd/I_a (Mean)	=	Ratio (K_3)
10.20	2.089		1.691		1.235
11.05	2.262		1.830		1.236
11-1/3	2.327		1.901		1.224
12.30	2.595		2.103		1.234
13.60	2.912		2.287		1.273
	Mean Ratio				1.24
	Standard Deviation				0.019

TABLE 25. BENCHMARK RATIO - SITE 10.

Frequency (kHz)	E_rd/I_a (Summary)	÷	E_rd/I_a (Mean)	=	Ratio (K_3)
10.20	2.089		1.914		1.091
11.05	2.262		2.053		1.102
11-1/3	2.327		2.065		1.127
12.30	2.595		2.372		1.094
13.60	2.912		2.622		1.111
	Mean Ratio				1.11
	Standard Deviation				0.015

VII. MISCELLANEOUS

EXIT BUSHING CAPACITANCE

1. Due to the lack of communication between the roof of the helix house and the antenna matching transformer enclosure, no measurement of the apparent capacitance (C_{app}) of the antenna was made.

2. It is believed that all of the measurements of C_{app} have been made with the assumption that the exit bushing capacitance was 150 pF, a value obtained long ago from the manufacturers. Since there was time and equipment available, a measurement of the exit bushing capacitance was made.

3. The exit bushing was measured with all the interior spark gap hardware in place and with the gap open (antenna ungrounded). See figure 12. The measuring element was the General Radio Type 722 N Precision Air Variable Capacitor using the General Radio Type 1650-A Impedance Bridge as a detector. In this kind of measurement, the precision is primarily a function of the incremental accuracy of the variable capacitor. The procedure is to:

   a. Balance the bridge with the bushing connected and the capacitor set to some low value, such as 100 pF.

   b. Disconnect the bushing, leaving all the connecting wires in nearly the same configuration.

   c. Rebalance the bridge using only the precision capacitor.

   d. The bushing capacitance is the difference in the readings of the precision capacitor in steps c and a.

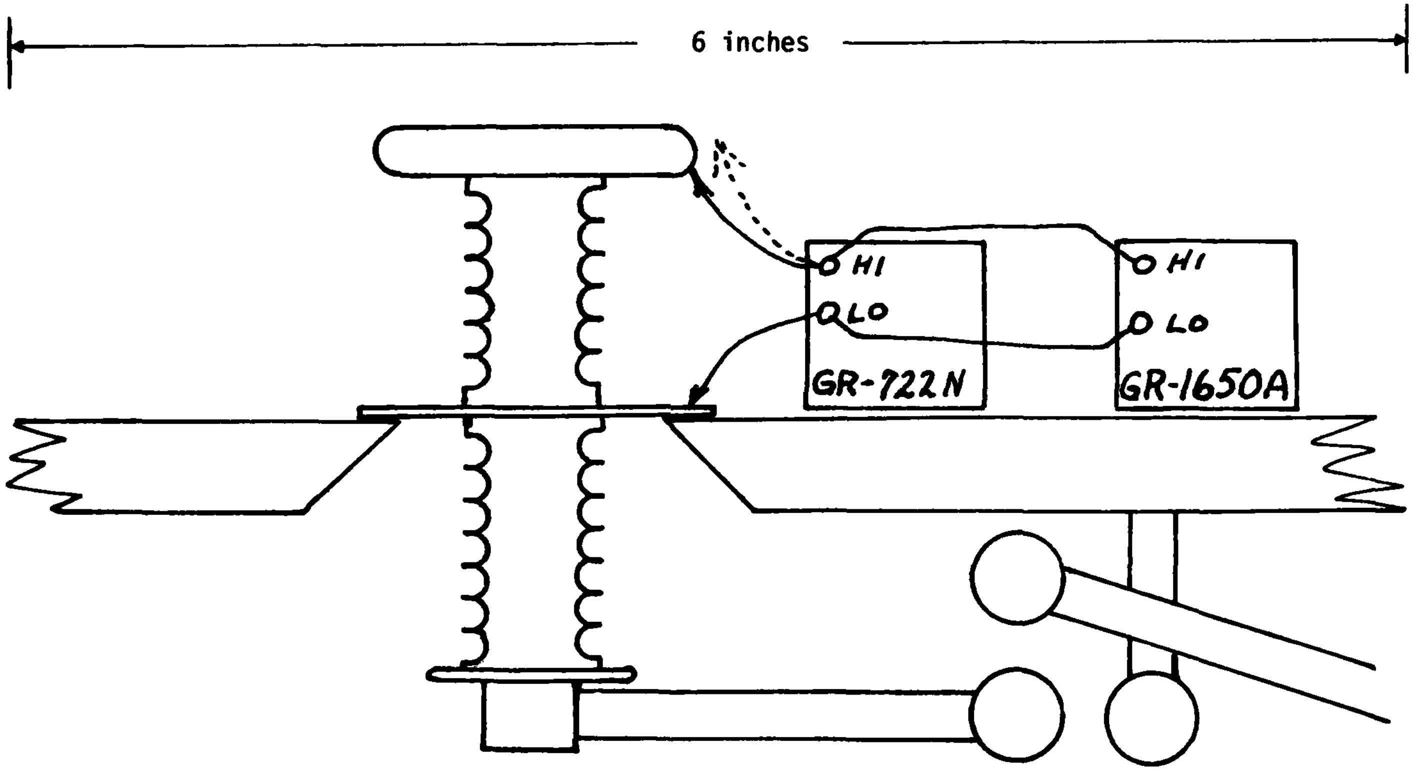


Figure 12. Capacitance measurements helix house bushing.

4. Two trials were made. Since the correlation was excellent, a mean was calculated. These measurements and calculations are given in table 26.

TABLE 26. CAPACITANCE MEASUREMENTS.

(Helix House Bushing, including Spark Gap Assembly)

First Trial:

C2	(Precision Capacitor alone)	388.6 pF.
C1	(Bushing and Precision Capacitor)	100.0 pF.
	Bushing Capacitance	288.6 pF.

Second Trial:

C2	(Precision Capacitor alone)	389.0 pF.
C1	(Bushing and Precision Capacitor)	100.0 pF.
	Bushing Capacitance	289.0 pF.

	288.6
	289.0
Mean Bushing Capacitance:	288.8 pF.

APPENDIX A. ABBREVIATIONS AND ACRONYMS

A	Amperes
Az	Azimuth angle, transmitter to measurement site
BIA	Base insulator assembly
C	Capacitance
ΔC	Capacitance change
C_{app}	Apparent capacitance (antenna)
cm	Centimeter
COGARD	Coast Guard
D	Distance (a readout)
d	Distance (km)
DME	Distance measuring equipment
DMU	Distance measuring unit
DSRC	Drive shaft revolution counter
E	Potential (volts)
E_g	Output voltage, signal generator (mV)
E_m	Field intensity, corrected for instrumentation (mV/m) (loop and vehicle factors)
E_r	Radiation field intensity, corrected to remove induction field (mV/m)
f	Frequency
FDP	Field distance product per ampere
h_e	Effective height (metres)
Hz	Hertz
I	Current (Amperes)
I_a	Current, antenna, corrected for losses in Helix House

I_{as}	Current, antenna system
in.	Inch
K_1	Ratio of I_a/I_{as}
K_2	Loop injection correction factor (1090/R)
K_3	Vehicle correction factor
kHz	Kilohertz
km	Kilometer
L	Inductance
ΔL	Induction change
L_H	Inductance of helix (mH)
L_T	Inductance required to resonate C_{app} at f (mH)
L_V	Inductance of variometer at position indicated (mH) (-cm = distance inner coil is down from the top)
m	Metre
mV	Millivolts
N	Number (of turns in an inductor)
OMSTA	OMEGA station
ONSOD	OMEGA navigation systems operations detail
P_r	Radiated power (kW)
P_v	Variometer position, cm down from the top
R_{as}	Antenna system resistance
R_r	Radiation resistance (ohms)
STA	Station (antenna)
S_x	Standard deviation
TR	Transponder
$\bar{x}$	Mean
ηas	Antenna system efficiency

APPENDIX B: EQUATIONS

1. Antenna Current

$$I_a = I_{as}K_1$$

2. Measured Field

$$E_m = E_g K_2 K_3$$

3. Radiation Field*

$$E_r = \frac{Em}{\left[1 + \left(\frac{300}{2\pi fd}\right)^2\right]^{1/2}}$$

4. Radiated Power

$$P_r = \left(\frac{E_r d}{300}\right)^2$$

5. Effective Height

$$h_e = \frac{10^4 E_r d}{4\pi I_a f}$$

6. Radiation Resistance

$$R_r = \frac{P_r \times 10^3}{I_a^2} \text{ or } \frac{1}{90}\left(\frac{E_r d}{I_a}\right)^2$$

7. Field Distance Product, Normalized

$$FDP = \frac{E_r d}{I_a}$$

*It is noted that this expression for correcting total field to radiated field applies for magnetic field type measurements, such as were performed in this work using a loop antenna. Although the results are given to E, electric field, strictly speaking H, magnetic field, was actually measured. The complete correction for E involves a 3rd term, not shown here.

8. Distance, Great Circle, Nautical Miles

$$d = 60 \cos^{-1} [\sin L_1 \sin L_2 + \cos L_1 \cos L_2 \cos (\lambda_2 - \lambda_1)]$$

(nautical miles × 1.83 = kilometres)

*(HEWLETT-PACKARD NAVIGATION PAC 1, NAV 1-10A)

9. Azimuth, Initial

$$A_z = \cos^{-1} \left[\frac{\sin L_2 - \sin L_1 \cos (d/60)}{\sin(d/60) \cos L_1}\right]$$

*(HEWLETT-PACKARD NAVIGATION PAC 1, NAV 1-10A)

10. Mean

$$\bar{x} = \frac{1}{n} \sum_{i=1}^{n} x_i$$

*(HEWLETT-PACKARD STANDARD PAC, STD 02A)

11. Standard Deviation

$$S_x = \sqrt{\frac{\sum_{i=1}^{n} x_i^2 - n\bar{x}^2}{n-1}}$$

*(HEWLETT-PACKARD STANDARD PAC, STD 02A)

---

*Equations 8, 9, 10, and 11 are all taken from the appropriate programs for the HP-65 calculator, which was used to prepare this report.

APPENDIX C: FIELD INTENSITY MEASUREMENTS, SUBSTITUTION METHOD
(Revision 1)

I. INTRODUCTION

This kind of Field Intensity Measurement is made feasible because of a method of calibrating field strength measuring equipment developed by Dinger and Garner of Naval Research Laboratory. This technique is described and justified in their NRL Memorandum Report 83, "A New Method of Calibrating Field Strength Measuring Equipment," dated 14 November 1952. Basically this method consists of injection of a constant current (high resistance source) into the loop shield which is considered to be unity coupled to the winding of the loop. A loop antenna, modified in accordance with illustrations given in this report, is employed. (See figure C1.) The signal path, for both the received signal and the calibrating signal, occupies common equipment eliminating the requirement of known gain from the antenna to the indicator. Only the value of a resistor in the loop modification and the accuracy of the voltmeter are required to establish the precision of the measurement. It is possible to determine both of these by independent means.

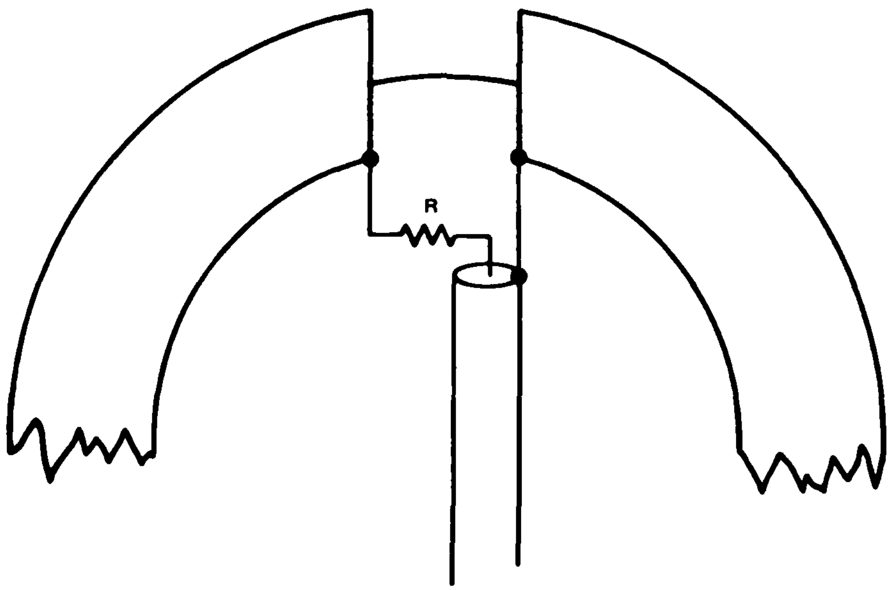


Figure C1

II. PROCEDURE

A. In Section B a step-by-step procedure for taking a measurement will be given. This procedure must be tempered by a certain amount of judgement based on experience. Experience is best gained by making a large number of measurements. However, some guidelines may be helpful:

1. Visual observation of fences, pipes, structures, power lines (especially those which could directly carry a signal from the transmitter to the measurement site) and the location of your own vehicle could show that a site is less than desirable.

2. One of the tests of a site is to orient the loop for a null (minimum signal on the indicator). The following two features of the null may indicate that a site is undesirable:

   a. The minimum signal level of the null is greater than 1% of the maximum signal.

   b. The direction of the null (right angle to the plane of the loop) is more than five (5) degrees from the direction to the transmitting antenna.

3. Compare the measured field strength with the expected field strength based on the design goals of the antenna. If there is a radical difference try other measurement sites nearby, correcting for any change in distance to the transmitting antenna. A large difference could be caused by invisible (possibly buried) conductors such as pipes or wires.

B. Select a site using the visual criteria of Section A.1.

1. Set up the loop antenna approximately 15 metres from the other measuring equipment in such a location that the direction to the transmitting antenna and the direction to the measuring equipment differ by approximately 90 degrees. (See figure C2).

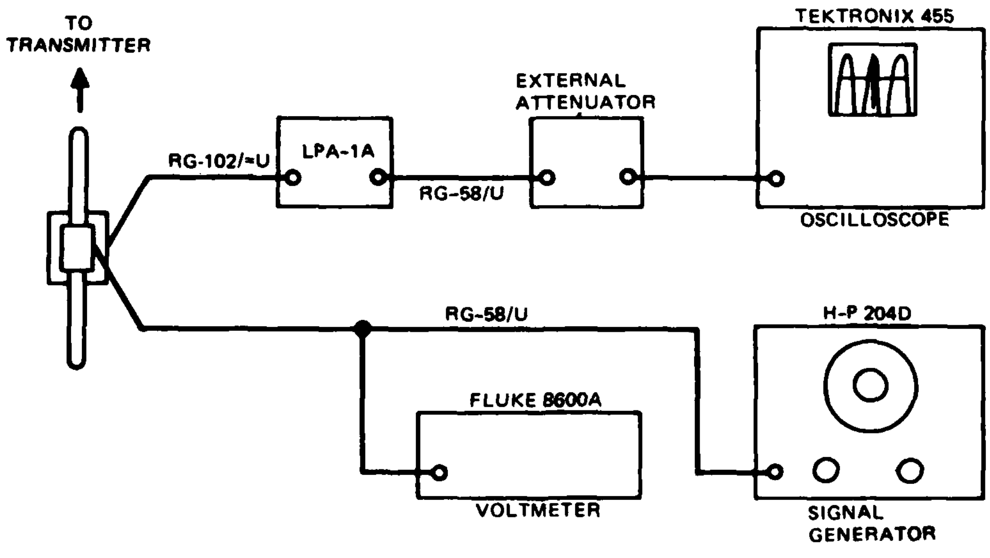


Figure C2

2. Set the Frequency Selector Switch, of the LPA-1A, to the frequency having the highest duty cycle. If f_t is being transmitted on four segments it would be used. If not, use the frequency on the segment having the longest duration.

3. Attach the LPA-1A external attenuator to the CH2 input jack of the Tektronix 455 Oscilloscope. Adjust the external attenuator to minimum loss (CW).

4. Set the controls of the oscilloscope as follows:

   a. Power Switch: DC, ON

   b. Horizontal Display: A

   c. Trigger Mode: AUTO

   d. Coupling Source: AC, Normal

   e. A Trigger Level: 0

   f. A and B Time/Div: 0.2 ms, Calibrated

   g. Intensity, Focus, Horizontal and Vertical Position: As necessary to center the display on the screen.

   h. Vertical Channel Selector: CH2

   i. Vertical Coupling Switch: AC

5. With the plane of the loop aimed at the transmitting antenna, set the oscilloscope vertical gain control to the Calibrated position and the vertical attenuator to produce an "on screen" waveform.

6. Calculate the attenuator setting and waveform size if the normal voltage was reduced to 1%. Set the vertical attenuator to this value.

7. Turn the loop approximately 90 degrees either direction then adjust the loop position for minimum signal (null) as indicated on the oscilloscope.

8. If the amplitude of the signal, at the null, is $\leq 1\%$ of step 5 check the bearing of the null (90 degrees to the plane of the loop). If the bearing of the null is within ±5 degrees of the direction to the transmitting antenna and the amplitude is $\leq 1\%$ the site is probably acceptable. If the site fails this test, move a few hundred metres, preferably at a constant distance to the station, and remeasure. Statistical tests, after all data are taken, may indicate anomalies not detected above.

9. If satisfied with the site, turn the plane of the loop toward the transmitting antenna to obtain the maximum signal.

10. Set the controls of the Tektronix 455 Oscilloscope as follows:

    a. Vertical Position: Full CCW (down)

    b. Vertical Attenuator: 10 mV/div, calibrated, AC

    c. A and B Time/Div: 20 μs, calibrated

    d. Adjust the LPA-1A External Attenuator control so the tips of the waveform are between 6 and 8 cm high.

    e. Adjust the horizontal position so one of the waveform tips is over the vertical centerline of the screen.

11. Turn the signal generator ON. Adjust the output of the generator to the exact frequency of the Omega signal selected by the loop amplifier (zero beat frequency).

12. Remove the signal generator output in the manner shown below:

a. If using a Hewlett-Packard 204D oscillator as a signal generator move the Range Selector switch to X 1K during periods of time that the generator voltage is unneeded. Do not switch OFF.

b. If using a special oscillator as a signal generator switch the frequency control to an intermediate step or switch the carrier OFF if a switch is available

13. Observe the tip of the waveform in the center for 2 or 3 successive pulses, noting the vertical position.

14. Turn the loop antenna to the null position. (If it is impractical to turn the antenna to the null position, such as is the case in a helicopter, the next step may be accomplished during the 200 ms spaces between transmissions.)

15. Return the signal generator output, that was removed in step 11, to the selected frequency. Adjust the signal generator output control to produce a waveform identical in amplitude to the one noted in step 12.

16. Read the digital voltmeter to obtain the value of the signal generator output. Enter this value on Data Sheet 5.

17. Switch the LPA-1A to each frequency being measured, repeating steps 9 through 15 for each frequency.

18. Transcribe the necessary information from Data Sheets 3, 4, and 5 to the appropriate spaces on Data Sheet 6. Perform the required calculations to complete Data Sheet 6.

Note: One or more Data Sheets may be required to calculate the distance from the transmitting antenna to the measurement site.

DATA SHEET 4-A

RADIO FIELD INTENSITY

SITE LOCATION

BENCHMARK & CALIBRATION

OMEGA STATION, ____________ DATE: ________

1. LOCATION OF MEASUREMENT: SITE NUMBER: ______

Description: ______________________________

2. GEOGRAPHIC COORDINATES: (Map or Chart Scale. 1: __________)

_____ ° _____ ' _____ " ( ) ____ . ______ = Lat. _____ . ________ ° ( )
(DD) (MM) (SS) (Inches) (DD) (dd)
Nearest Lat. Line ± Dist. to position N or S

______ . ______ ( ) ____ . ______ = ________ . ______ ( )
Nearest Metric Grid (MM) (m)

_____ ° _____ ' _____ " ( ) ____ . ______ = Long. _____ . ________ ° ( )
(DDD) (MM) (SS) (Inches) (DDD) (dd)
Nearest Long. Line ± Dist. to Position E or W

______ . ______ ( ) ____ . ______ = ________ . ______ ( )
Nearest Metric Grid (MM) (m)

3. LOCATION OF TRANSMITTING ANTENNA:

Description, if other than tower.

Lat. _____ . ________ ° ( )
(DD) (dd)
N or S

Metric Grid ________ . ______ ( )
(MM) (m)

Long. _____ . ________ ° ( )
(DDD) (dd)
E or W

Metric Grid ________ . ______ ( )
(MM) (m)

4. SIGNAL PATH; TRANSMITTER TO RECEIVER SITE: Azimuth: ________ °T. Distance: ________ km.

DATA SHEET 4-B

RADIO FIELD INTENSITY

SITE LOCATION

D M E BASELINE

OMEGA STATION, ____________ DATE: ____________

RADIAL NUMBER: ________

1. LOCATION OF TRANSPONDERS.

No. 1 (Map or Chart Scale. 1:____________)

____ ° ____ ' ____ " ( ) ____ . ____ = Lat. ____ . ____ ° ( )
(DD) (MM) (SS) (Inches) (DD) (dd)
Nearest Lat. Line ± Dist. to position N or S

____ . ____ ( ) ____ . ____ = ____ . ____ ( )
Nearest Metric Grid (MM) (m)

____ ° ____ ' ____ " ( ) ____ . ____ = Long. ____ . ____ ° ( )
(DDD) (MM) (SS) (Inches) (DDD) (dd)
Nearest Long. Line ± Dist. to Position E or W

____ . ____ ( ) ____ . ____ = ____ . ____ ( )
Nearest Metric Grid (MM) (m)

No. 2 (Map or Chart Scale. 1:____________)

____ ° ____ ' ____ " ( ) ____ . ____ = Lat. ____ . ____ ° ( )
(DD) (MM) (SS) (Inches) (DD) (dd)
Nearest Lat. Line ± Dist. to Position N or S

____ . ____ ( ) ____ . ____ = ____ . ____ ( )
Nearest Metric Grid (MM) (m)

____ ° ____ ' ____ " ( ) ____ . ____ = Long. ____ . ____ ° ( )
(DDD) (MM) (SS) (Inches) (DDD) (dd)
Nearest Long. Line ± Dist. to Position E or W

____ . ____ ( ) ____ . ____ = ____ . ____ ( )
Nearest Metric Grid (MM) (m)

2. TRANSPONDER BASELINE, 1 TO 2. Azimuth: ____ . ____ °T.

Distance: ____ . ____ km.

DATA SHEET 4-C

RADIO FIELD INTENSITY

SITE LOCATION

ANTENNA TO TRANSPONDER BASELINE

OMEGA STATION, ____________________

DATE: ____________

RADIAL NUMBER: ________

1. LOCATION OF TRANSMITTING ANTENNA. (Map or Chart Scale. (1: __________)

____ ° ____ ' ____ " ( ) ____ . ________ = Lat. ____ . ________ ° ( )
(DD) (MM) (SS) (Inches) (DD) (dd)
Nearest Lat. Line ± Dist. to Position N or S

________ . ____ ( ) ____ . ________ = ________ . ____ ( )
Nearest Metric Grid (MM) (m)

____ ° ____ ' ____ " ( ) ____ . ________ = Long. ____ . ________ ° ( )
(DDD) (MM) (SS) (Inches) (DDD) (dd)
Nearest Long. Line ± Dist. to Position E or W

________ . ____ ( ) ____ . ________ = ________ . ____ ( )
Nearest Metric Grid (MM) (m)

2. LOCATION OF TRANSPONDER 1
(From DS-4-B)

Lat. ____ . ________ ° ( )
(DD) (dd)
N or S

Metric Grid ________ . ____ ( )
(MM) (m)

Long. ____ . ________ ° ( )
(DDD) (dd)
E or W

Metric Grid ________ . ____ ( )
(MM) (m)

3. TRANSMITTING ANTENNA TO TRANSPONDER 1.

Azimuth: ____ . ________ °T.

Distance: ____ . ________ km.

DATA SHEET 4-D

RADIO FIELD INTENSITY

SITE LOCATION

MEASURED BY D M E

OMEGA STATION, ______________________ DATE: ____________

1. LOCATION OF MEASUREMENT SITE NUMBER: ____________

Description: ____

2. TRANSPONDER 1 to 2 BASELINE: Azimuth _____ . ________________ ^{o}T.

Distance _____ . ________________ km.

3. ANTENNA TO TRANSPONDER 1: Azimuth _____ . ________________ ^{o}T.

Distance _____ . ________________ km.

4. DMU READINGS: D_1 __________ km, D_2 __________ km.

5. CALCULATED POSITION OF VEHICLE, ANTENNA TO VEHICLE.

Distance _____ . _____ km.

Azimuth _____ . _____ ^{o}T.

DATA SHEET 5 (DS-5)

RADIO FIELD INTENSITY MEASUREMENTS

OMEGA STATION:______________ SITE NO.____ DATE:______________________

I_{as}________ A. K_1 ____ . _____ K_2 ____ . _____ K_3 ____ . ____

LOOP HEIGHT ____________ (m./ft.) TRIPOD ______ HELICOPTER _______
(ABOVE: SURFACE - SEA LEVEL)

TYPE OF MEASUREMENT: HELICOPTER CAL. ___ BENCHMARK ___ ROUTINE ___

TIME (LOCAL)	FREQUENCY (kHz)	E_g (mV)	HEADING (Mag.)	D M E D1	D2	DIST. km.	AZ. °T.
	10.20						
	13.60						
	11.1/3						
	11.05						
	F_t						

	10.20						
	13.60						
	11-1/3						
	11.05						
	F_t						

	10.20						
	13.60						
	11-1/3						
	11.05						
	F_t						

COMMENT

DATA SHEET 6 (DS-6), REV 1

RADIO FIELD INTENSITY CALCULATIONS

HELICOPTER CAL. ______. BENCHMARK ______ ROUTINE ______

LOOP HEIGHT ______ (m./ft.) TRIPOD ______ HELICOPTER ______

(Above Surface/S.L.)

OMEGA STATION: ______________ SITE NUMBER: ______________ DATE: ______________

Distance: ______ . ____ km., K_1 = ______ K_2 = ______ K_3 = ______
(If constant)

I_a/I_{as} Loop Factor   Vehicle Factor

Dist. (km.)	Freq. (kHz)	I_{as} (A)	E_g (mV)	I_a (A)	E_m (mV/m)	E_r (mV/m)	P_r (kW)	h_e (m)	R_r (Ohm)	$E_r d/I_a$ (Units)
.	10.20									
.										
.										
.	13.60									
.										
.										
.	11-1/3									
.										
.										
.	11.05									
.										
.										
.										
.										
.										
.										
.										

APPENDIX D: ANTENNA CURRENT MEASUREMENTS, SUBSTITUTION METHOD (Revision 1)

I. INTRODUCTION

1. The Omega transmission consists of a series of pulses whose lengths are between 900 and 1200 milliseconds, inclusive. Very few measuring instruments respond quickly enough to allow direct measurement to the degree of precision desired. One of the more simple methods of measuring a current or voltage is to employ an indicator (oscilloscope) that responds quickly to the signal being measured, a means of storage (operator's memory) and a signal source, known to have good waveform, that may be substituted for comparison. (See figure D1.) In this method it is required to know the accuracy of the current-to-voltage transducer ($\leqslant 1\%$), the accuracy of the voltmeter ($\leqslant 1\%$) and the precision with which the comparison can be made ($< 1\%$).

2. A new current-to-voltage transducer is being permanently installed on the ground leg of the antenna tuning system. This device has an output of 0.01 volt per ampere and is accurate to $< 1\%$. Its purpose is primarily to provide a means of accurately measuring antenna current in order to calibrate the panel meters in the Timing and Control racks. However, during field measurement activities it will be used to provide antenna current data directly.

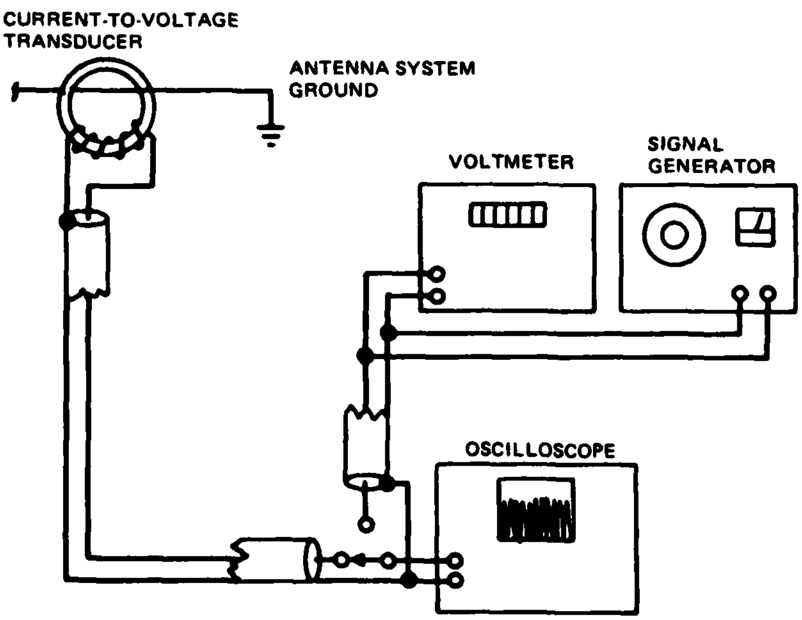


Figure D1

II. PROCEDURES

A. BASIC CURRENT MEASUREMENT

1. Assemble the equipment as shown in figure D1.
2. Set the frequency of the signal generator to 12 kHz.
3. Set the controls of the Tektronix 455 Oscilloscope as follows:
   a. Horizontal Display: A
   b. Trigger Mode: AUTO
   c. Coupling Source: AC-Normal
   d. A Trigger Level: 0
   e. A and B Time/Div: 1 ms, calibrated
   f. Vertical Mode: CH2
   g. Input Selector Switch: AC
   h. Vertical Position (CH2): Full down (CCW)
   i. Vertical attenuator and variable control: As necessary to position the top of the w`veform being measured approximately 7 cm from the bottom of the screen.
   j. Test the frequency response of the vertical presentation over the range of Omega frequencies to be sure that the comparisons may always be made at 12 kHz. (An error was once found, in an oscilloscope, over the range of 10 to 14 kHz.)

4. With the output of the current-to-voltage transducer connected to the vertical input of the oscilloscope adjust the oscilloscope as required by step 3i. Note the position of the top of the waveform being measured.

5. Without disturbing any of the oscilloscope controls, disconnect the transducer and connect the cable from the signal generator and voltmeter to the vertical input.

6. Adjust the output attenuator and variable control of the signal generator to produce a display of the same amplitude noted in step 4.

7. Read the voltage required in step 6 and divide the value by 0.01 to obtain the current in amperes. (Note that even though the comparisons are being done by peak measurements the voltmeter readings, in volts rms, are valid because the waveforms are essentially sine waves.)

8. Repeat steps 4 through 7 for each frequency being transmitted.

9. Record all the data required by Data Sheet 3 on that sheet. The time interval will be specified by the person in charge of the field intensity measurements.

B. CURRENT MONITORING FOR FIELD INTENSITY MEASUREMENTS

1. Set up the equipment as shown in paragraphs A 1, 2, and 3 above.

2. Choose the one highest value of antenna current that will be possible to hold all day for all frequencies. Typically this will be the maximum current that may be so maintained on 10.2 kHz.

3. Multiply this value of antenna current by the transfer factor of the current-to-voltage transducer to obtain the required output voltage from the signal generator. Adjust the signal generator to this value.

4. Connect the signal generator to the oscilloscope. Adjust the vertical gain control of the oscilloscope to place the top peaks of the waveform on the second highest horizontal line of the graticule. Do NOT change the vertical position control from the full down (CCW) position.

5. Switch the oscilloscope from the signal generator to the current-to-voltage transducer.

6. Using the individual and master attenuators of the Timing and Control Set, adjust the current of each frequency so the peaks of each waveform touch the same line chosen in paragraph B4. This ensures that all frequencies are at the same current and may be maintained there during the entire period of field measurements.

7. Periodically recheck the calibration of the oscilloscope as in paragraph B4. Experience and the stability of the oscilloscope will determine the frequency of recalibration.

8. Using the procedure of this section reduces the amount of logged data and also the opportunity for error. Only the chosen current, or a new current if necessary, need be logged and time noted.

III. CONCLUSIONS

1. Procedure A is most useful during routine operation to verify the accuracy of the antenna current meters of the Timing and Control Set.

2. Procedure B is preferred during field intensity measurements because, in addition to the previously noted advantages, it simplifies the calculation procedures.

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DATA SHEET 3

RADIO FIELD INTENSITY

ANTENNA CURRENT

DATE: ______________

OMEGA STATION: ______________________ SHEET NUMBER: ______

ANTENNA SYSTEM CURRENT (I_{as})

TIME (Local)	10.20 (kHz)	13.60 (kHz)	11-1/3 (kHz)	11.05 (kHz)	F_t ______ (kHz)

APPENDIX E: FIELD INTENSITY MEASUREMENTS BY HELICOPTER
(Revision 1)

I. INTRODUCTION

1. Some of the Omega stations are located in sites which are almost impossible to measure on the ground. These are either volcanic islands such as Hawaii and Reunion, the mountainous island of Tsushima, or the mountainous coast of Norway. These areas, besides being almost impassable, are characterized by poor and variable ground conductivity. These conditions dictate a measurement site remote from the poorly conducting ground plane and above the impassable terrain. Due to the low duty cycle pulses of the Omega signals a moving vehicle (fixed wing aircraft) is a very unattractive platform. The length of time required to obtain an accurate measurement requires a stationary platform. Above the terrain this means a helicopter.

II. INSTRUMENTATION

1. To reduce the pattern distortion, and consequent calibration factors, it is desirable to mount the loop antenna as far from the helicopter structure as practical, while placing the null of the antenna pattern directly on the largest noise source of the vehicle.

2. Each kind of helicopter presents its own set of mounting problems. It is practical to position the loop approximately five (5) feet from either side of the cabin. Additionally the loop should be mounted on the side opposite the tail rotor in case of a mounting failure. While the Hughes 500C helicopter produced no noise problems, with the loop mounted parallel to the longitudinal axis, other helicopters did. In these cases the loop was oriented to pick up the least noise from the helicopter. Since the Hughes 500C was available at both Norway and North Dakota, the mounting (to the steps) was designed to telescope and rotate while keeping the loop in a fixed position relative to the helicopter. Mounting to other helicopters must be arranged on site if a specimen is not available prior to departure. A rotating mount for the loop must be provided to allow positioning the null on the noise source. It is important that the mounting hardware be made of insulating material and the fastenings be nonmagnetic. The loop and mounting assembly must withstand forward speeds of 100 knots and also the down wash of the main rotor.

3. All wires and cables, associated with the loop assembly, must be secured in such a manner that they will withstand the airstream during flight. They should be spirally wrapped around tubular sections, of the loop mount, to aid in vortex shedding.

III. PROCEDURE

A. CALIBRATION

1. Calibration of the helicopter mounted loop must precede measurement flights. It should be done as near the station as practical in order to have a strong, noise free signal. The suggested distance would be 18 to 22 kilometres.

2. All the equipment necessary for field intensity measurements shall be aboard the helicopter. A tripod mounted loop antenna is placed about 15 metres from the

helicopter at a position that places the helicopter in the null of the antenna pattern when the plane of the loop is aimed at the station. Auxiliary cables, approximately 15 metres in length, are used to connect the tripod mounted loop to the measuring equipment in the helicopter.

3. Have the antenna current monitored and maintained, by the substitution method outlined in Appendix D, Section II B, and entered on Data Sheets 5 and 6.

4. Perform Field Intensity measurements, using the substitution method of Appendix C, with the tripod mounted loop. Record the readings on Data Sheet 5.

5. Transcribe the required values to Data Sheet 6 and, using 1.0 for K_3, calculate $E_r d/I_a$ for each frequency.

6. Disconnect the external antenna and connect the helicopter antenna to the measuring equipment.

7. Lift the helicopter off the ground and hover with the loop at the same height, and over the same position, as the tripod mounted loop. Swing the helicopter right and left to determine the direction of maximum signal. Do not try to get a null.

8. With the helicopter hovering in the direction of maximum signal measure all frequencies. Record the data on Data Sheet 5.

9. Transcribe the necessary data to Data Sheet 6 and, using 1.0 for K_3, calculate $E_r d/I_a$ for each frequency.

10. Divide the values determined in step 5 by the values determined in step 9 to obtain the true value of K_3, the Vehicle Correction Factor.

11. Repeat steps 7 through 10 with the helicopter pointed away from the station.

B. MEASUREMENTS

1. The determination of distance from the measurement site to the transmitting antenna is very important.

a. If a position can be found on a chart or map it may be described in terms of latitude and longitude or a grid system. Since coordinates of the transmitting antenna are known the distance may be calculated by great circle navigation equations or by rectangular to polar conversion.

b. Over water, over land which has few identifiable features, or over land at altitudes high enough to make visual positioning difficult, it is necessary to use radio distance measuring equipment to establish position. Any number of simple triangulation and vector addition calculations may be used to obtain the distance and azimuth of the measurement site from the transmitting antenna.

2. The altitude chosen for measurements is a compromise value – high enough to ensure readings unaffected by changes in altitude and low enough for accurate maintenance of position by visual reference. One thousand (1000) feet above the terrain has been selected for helicopter operations using visual position fixing.

3. The step-by-step procedure used to obtain a measurement follows:

a. Choose the location over which the measurement is to be taken. Note a sufficient number of landmarks to facilitate maintenance of the position.

Over water it might be advisable to drop a floating smoke generator or dye marker to provide a visual reference.

b. Tune in the Omega frequency having the longest duty cycle. Swing the helicopter (loop) plus or minus a few degrees about the estimated direction to the station to establish the direction of the maximum signal.

c. Point the helicopter in the direction of the maximum signal while hovering over the exact position of the site at the chosen altitude.

d. Perform the substitution type field intensity measurements on all the frequencies desired.

e. Most helicopters are difficult to control in a hover with the wind from behind. In some cases it will be necessary to use the tail toward the station orientation. Be sure to use the correct Vehicle Factor (K_3) for this direction.

APPENDIX F: REV. 1

MEASUREMENT OF ANTENNA TUNING SYSTEM GEAR RATIOS

I. INTRODUCTION

Gear ratios for the gear boxes of the Antenna Tuning Set were calculated under the assumptions that the required inductance change is an exact inverse function of frequency, that each variometer was operating in the same part of its travel and the inductance change is linear. In practice none of these assumptions are correct but provided a starting point to allow preliminary operation and test. After installation and preliminary operation, the necessity of adjustment of the calculated values becomes apparent. As the antenna capacitance changes, from any cause, the antenna tuning will attempt to keep all the frequencies tuned simultaneously. When the antenna capacitance changes, if the gear ratios are incorrect, there will be hunting back and forth as each frequency is keyed. This not only causes unnecessary wear in the tuning system components but, if the error is large, can prevent the antenna from being tuned during the short period of one transmission segment. The procedure reported herein allows selection of the best gear ratios from the sprockets available.

II. MEASUREMENT

A. EQUIPMENT

1. An adding and subtracting turns counter is mounted on the main drive right angle support frame in Room 101. This should be direct drive and indicate 1/10 turn of the shaft.

2. A switchable step capacitor is attached to the antenna near the exit bushing. If any prior knowledge of the excursion of the antenna capacitance is available, try to adjust the added capacitance to this value. If no prior knowledge is available, use the maximum capacity change that will allow the variometers to operate in the reasonably linear, or useful, range. The plate spacing, however, must be sufficient for the minimum voltage that will allow proper automatic antenna tuning. If the new switchable test capacitor is used, spacing gauge blocks are provided for 1, 1-1/2 and 2 inch spacings. Minimum spacing is approximately 1/2 inch and maximum approximately 2-1/2 inches. Table F1 gives estimated capacitances at various spacings.

TABLE F1

Spacing (inches)	Estimated Capacitance (pF)	Measured Capacitance (pF)
0.5	1000	------
1.0	520	585
1.5	360	405
2.0	280	322
2.5	230	272

B. PROCEDURE

1. Disengage all of the clutches, in the variometer rooms, except the clutch to the variometer gear box being tested.

2. Adjust the transmitter output to the minimum value that will allow good antenna tuning and will allow the servo motor to start running, in the proper direction, to retune the antenna when the test capacitor is switched in or out of use.

3. With the test capacitor switch OFF, allow the antenna to be tuned automatically.

4. Read the main shaft revolution counter and enter the number on the appropriate line of Data Sheet F1 Rev 1.

5. Change the test capacitor switch to ON and allow the antenna to be tuned automatically.

6. Read the main shaft revolution counter and enter the number on the appropriate line of Data Sheet F1 Rev 1.

7. Enter the difference in the two counter readings, without sign, on a line of Data Sheet F1 Rev 1 between the two counter readings. This column is labeled "Drive shaft rotation" in turns.

8. Change the test capacitor switch to OFF and allow the antenna to be tuned automatically.

9. Read the main shaft revolution counter and enter the number on the next appropriate line of Data Sheet F1 Rev 1.

10. Perform the same subtraction and entry as in step 7.

11. This completes one full cycle of readings and produces two (2) values of "Drive shaft rotation."

12. Repeat steps 3 through 10 until satisfied that a good mean value may be calculated.

13. Calculate the mean value of the column of numbers labeled "Drive shaft rotation." Enter the mean value on the appropriate lines of Data Sheet F1 Rev 1 and F2 Rev 1.

14. Repeat steps 1 through 13 for each frequency. If this test is being made at the same time as installation of 11.05 kHz connect the chain to the sprockets for 11-1/3 kHz, in the variometer room for 11.05 kHz, as a temporary measure.

15. Enter the actual gear ratios used for this test on appropriate lines of Data Sheet F2 Rev 1.

16. The Data Sheets of this appendix will probably be reproduced as tables in a report of this test.

III. CALCULATION

1. Multiply the MDSR by the installed gear ratio, or the ratio actually used for this test, to obtain the number of turns the lead-screw made to retune the antenna (LSR). Enter these numbers in the LSR column of Data Sheet F2 Rev 1.

2. Choose the LSR for 13.60 kHz as the value of LSR (Reference). See Note 1 of Data Sheet F2 Rev 1. Divide the LSR (Turns) by the LSR (Ref.) to obtain the value of the LSR Ratio. Enter this number in the proper column of Data Sheet F2 Rev 1 and the appropriate line of Data Sheet F4 Rev 1.

3. Calculate all of the possible gear ratios, using the sprockets that are available at the station, and tabulate in ascending order on Data Sheet F3 Rev. 1.

4. Assign the lowest available gear ratio, from Data Sheet F3 Rev 1, to 13.60 kHz on Data Sheet F4 Rev 1. Multiply this gear ratio by the LSR ratio, for each frequency, entering these new values on the line for the Required Ratio in appropriate columns of Data Sheet F4 Rev 1. Continue assigning higher values to the column for 13.6 kHz until the calculated value of gear ratio required for 10.20 kHz exceeds the highest gear ratio available.

5. Tabulate the nearest available gear ratio immediately under the required gear ratio. Calculate the errors for each frequency on each line. Select the line with the smallest peak to peak error as the selected set of gear ratios. Install the sprockets indicated, for each selected ratio as shown on Data Sheet F3 Rev 1, in the appropriate variometer room.

6. If there are enough sprockets, install pairs of these new sprocket selections in the spare variometer room (106). If not, try the selection having the next higher error for the spare variometer room.

DATA SHEET F1 REV. 1

Frequency (kHz)	ΔC (____ pF)	Main Shaft Counter Readings (Turns)	Drive Shaft Rotation (Turns)
________	OFF	NNN · nn	
			NN · nn
	ON	____ · __	
			___ · __
	OFF	____ · __	
			___ · __
	ON	____ · __	
			___ · __
	OFF	____ · __	
			___ · __
	etc.		

Mean drive shaft revolutions (MDSR) ___ · __

DATA SHEET F2 REV. 1

Frequency (kHz)	MDSR (Turns)		Installed Gear Ratio (2)		LSR (Turns) (2)		(1&2)		LSR Ratio between Frequencies (2)
10.20	NN · nn	X	N · nnnnn	=	NN · nnnn	÷	LSR (Ref.)	=	N · nnnnn
11.05	___ · ___	X	___ · _____	=	___ · _____	÷	LSR (Ref.)	=	___ · _____
11-1/3	___ · ___	X	___ · _____	=	___ · _____	÷	LSR (Ref.)	=	___ · _____
f_t	___ · ___	X	___ · _____	=	___ · _____	÷	LSR (Ref.)	=	___ · _____
13.60	___ · ___	X	___ · _____	=	___ · _____	÷	LSR (Ref.)	=	___ · _____

NOTE 1. While any one of the LSR values may be chosen it is easier to use the value of 13.60 kHz to produce whole number ratios for the next step.

NOTE 2. Even though the precision of measurement does not warrant it, keep at least 6 significant figures to avoid rounding errors.

DATA SHEET F3 REV. 1

Available Gear Ratios

Gear Ratio	Sprocket Teeth (Input-Output)	Gear Ratio	Sprocket Teeth (Input-Output)
0.61111	33-54		
0.63462	33-52		
–			
–			
–			
–			
1.44444	52-36		
1.45455	48-33		
etc.			

DATA SHEET F4 REV. 1

Required gear ratios

Available gear ratios

Peak to peak error of each selected set

Frequency (kHz)	13.60	ft	11-1/3	11.05	10.20
LSR Ratio	1.00000	1.46362	1.60990	1.70495	2.08270
Required Ratio	0.61111	0.89443	0.98383	1.04191	1.27276
Available Ratio		0.88889	1.00000	1.04167	1.22727
Error (%)	5.35 p-p	-0.62	+1.64	-0.02	-3.71
Required Ratio	0.63462	0.92884			
Available Ratio		0.92593	etc.		
Error (%)		-0.32			

NOTE 1. When making selections from a limited number of sprockets which are available it is possible that large errors will appear on some lines. Visual inspection will allow the calculation to be stopped on that line, saving some effort.

APPENDIX G. POSITION FIXING OF A VEHICLE BY RADIO DISTANCE MEASURING EQUIPMENT (DME)

I. INTRODUCTION

1. In order to calculate the radiated power of a transmitting station, it is necessary to make field intensity measurements (FIM) of the radiated signal and to precisely know the distance between the transmitting and measuring antennas.

2. The usual vehicle used to measure field intensity above the surface of the Earth is the helicopter because of its capability of remaining stationary over a position while many measurements are made.

3. Visual determination of the precise position at the usual altitudes of 300 to 1000 meters is very difficult. The use of general purpose forms of radio navigation is neither as precise or as fast as desired.

4. DME, such as the Trisponder manufactured by Del Norte Technology, is capable of producing suitable measurements that satisfy both the precision and speed requirements.

5. An additional on-board computer (programmable calculator) is required to calculate the distance and azimuth from the transmitting antenna.

II. REQUIREMENTS

1. For a number of reasons, FIM, on frequencies in the 10 to 14 kHz navigation band, are conducted at distances of 20 to 40 kilometers from the

transmitting antenna. To ensure a reasonable amount of accuracy in the final calculations, an attempt is made to limit each contributing error to a practical minimum.

2. The parameters measured to calculate radiated power are tabulated in order of increasing difficulty in measurement accuracy.

a. Distance from the transmitting antenna

b. Antenna current

c. Field intensity.

3. At the measurement ranges, an error of ±0.5% is 100 to 200 meters. It should be easy to do better, probably near ±0.25%.

4. The azimuth must be known, to a lesser accuracy, to identify the radial direction of the measurement.

III. METHOD

A. INTRODUCTION

1. The method chosen consists of triangulation to locate the helicopter on a vector from a transponder location; and vector addition to locate the helicopter with respect to the transmitting antenna. This solves the problem for both azimuth and distance. All of the position measurement is done in the helicopter; facilitating navigation to a position for FIM and ensuring simultaneous position fixing with the FIM.

B. RANGE SELECTION

1. Two transponder locations are chosen near the measurement area. Consideration is given to the "line of sight" requirement of the DME and to the geometrically acceptable operational area as shown in figure G-1. Figure G-1 is constructed as follows:

a. Using a drafting compass, set the drawing radius to the distance along the baseline.

b. Strike arcs above and below the baseline at intersecting points.

c. From the two intersecting points draw arcs, as shown in figure G-1, between the transponder positions.

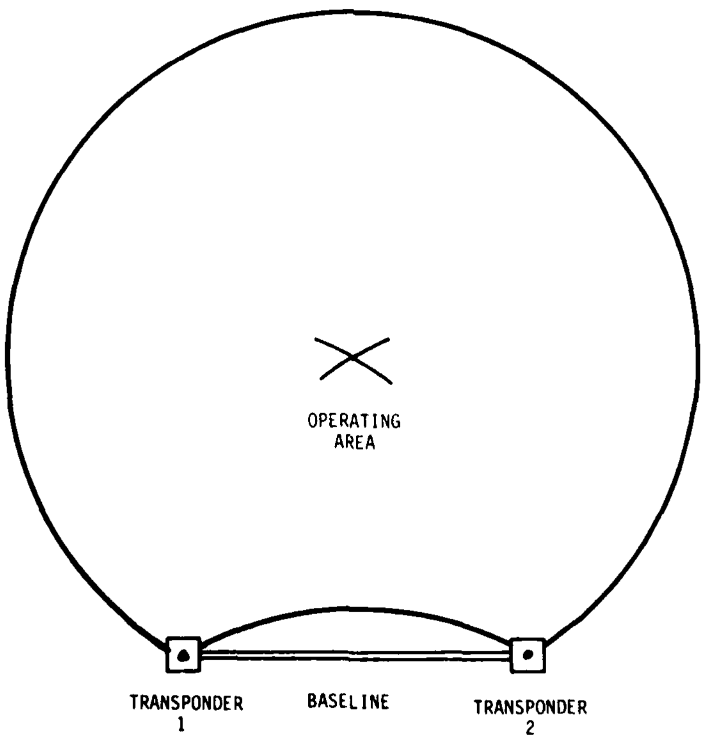

Figure G-1.

2. The operating area, for FIM along a radial, must fall in the area bounded by the arcs.

3. Check the coverage of the transponder antennas to ensure that the intended operating area is within the pattern angle. If using 180° antennas there should be no problem. With 90° antennas some of the geometrically correct area will not be covered.

4. The transponder location nearest the transmitting antenna is usually defined as the primary and is used to obtain D1 on the distance measuring unit (DMU) in the helicopter. The transponder baseline is now the vector from the primary (D1) to the secondary (D2) transponder. Triangulation is done on this baseline.

5. *The azimuth and distance from the transmitting antenna to the* D1 transponder is the second vector and will be added to the D1 to helicopter vector.

C. PREFLIGHT PREPARATION

1. Select all transponder sites.
2. Calculate the transponder baseline azimuths and distances between all the transponder pairs to be used.
3. Calculate the baseline azimuths and distances from the station to the primary transponder of each pair.
4. If the positions of the transponders and the station are in grid coordinates, be sure to add the grid correction to obtain true North.

5. Record baseline data and solution steps on a program card of the on-board computer (calculator). Label the card and protect it against accidental erasure.

6. To check for gross errors, either in program or baseline data on the cards, it is advisable to perform a test position solution obtaining D1 and D2 by measurement on a map, checking the solution on a map.

D. FLIGHT PROCEDURES

1. After take-off, use deduced reckoning to navigate the helicopter to the proposed site of measurement. Deploy the DME antenna if required to be retracted while on the ground.

2. On estimated arrival at the site, measure D1 and D2. Calculate the position and give corrective directions to the pilot.

3. After confirmed arrival over the site, the pilot will pick a hover reference point and try to stay at the site. Over water, a marker (preferably dye) should be dropped in the water as a hover reference.

4. The DME should be allowed to run in the AUTO mode until a FIM reading is completed; then switched to MANUAL to lock the readings until they may be recorded.

IV. CALCULATIONS, ERRORS AND PROGRAMS

A. CALCULATIONS

1. In position determination by DME, the known values are the baseline azimuth, the baseline length and the two remaining sides of a triangle. The known values of the triangle are the three sides. The law of cosine is used to calculate the angle between the baseline and the vector to the helicopter from the primary (D1) transponder. This angle is added to the azimuth of the baseline to obtain the true azimuth from D1 to the helicopter. The distance to the helicopter from D1 is measured directly by the distance measuring unit (DMU) located in the helicopter.

2. To obtain the location of the helicopter, with respect to the transmitting antenna, the station to D1 vector is added to the D1 to helicopter vector. The resultant vector is the azimuth and distance from the station to the helicopter.

B. ERRORS

1. Several sources of errors are present in this method of position fixing. They are, but not necessarily limited to, the following:

   a. Errors in the maps used to determine the range parameters and in the locations plotted on them

   b. Ranging errors by the DMU

   c. Slant range versus true horizontal distance when the helicopter and transponders are at different heights

d. Calculation errors caused by using a finite number of significant figures, and

e. Errors in rounding off the calculated values to provide a practical display.

They may be minimized, disregarded as inconsequential, or accepted as a contribution to the total error.

2. Map errors of cartography are not known so are not considered. Errors in printing, caused by paper shrinkage, may be corrected by measurement and calculation of a scale change. The use of precision calipers or dividers helps minimize the plotting errors. In any case, it is estimated that a position may be located, on a map having a scale of approximately 1:25000, to a precision of ±10 meters.

3. The Del Norte Technology DME, after being calibrated on a test range, is expected to be within 3 meters of the indicated ranges at distances of 100 meters through 80 kilometers. It is claimed that, in practice, the error is most likely 1 meter or less at ranges of 150 meters to 70 kilometers. These errors are inconsequential.

4. Slant range errors may be kept to values small enough to be ignored by selection of the transponder locations. If possible, select positions as close as possible to the operating altitude of the helicopter. If this is not possible, keep the distance between the helicopter and the transponder large; for example, at 20 kilometers, with a difference in height of 500 meters. The error is 6.25 meters. Try not to allow the slant range error to exceed 10 meters. Of course, a powerful on-board computer can correct for slant range errors.

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OMEGA LA REUNION ANTENNA SYSTEM: MODIFICATION AND VALIDATION TE--ETC(U)
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UNCLASSIFIED NOSC-TR-484-VOL-1 NL

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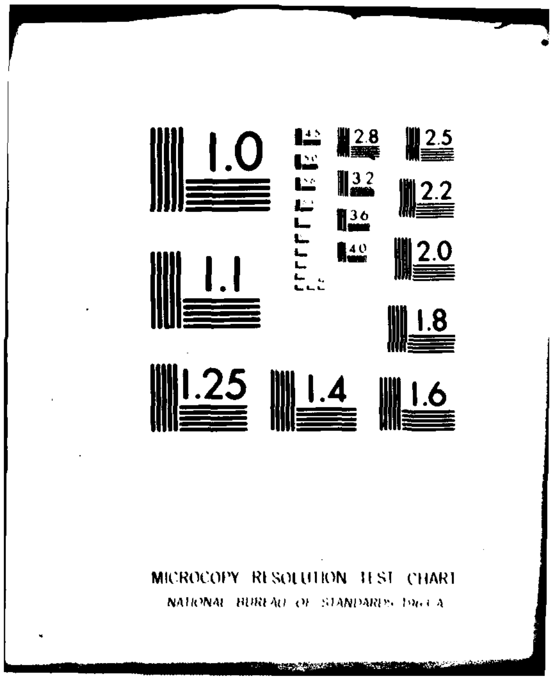
1.0
1.1
1.25
1.4
1.6
1.8
2.0
2.2
2.5
2.8
3.2
3.6
4.0
MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS 1963 A

5. By using calculators or computers which perform calculations using 10 or more significant figures, instead of plotting position, the calculation errors are minuscule.

6. In the program to be presented later, the displayed azimuth is improperly rounded, which results in possible errors of almost 1 degree. Since the azimuth is only used to identify the radial direction, and the distance is properly treated, this is also unimportant.

7. In summary, the largest contribution to the total error is in locating the transponders by map interpretation. If it is possible to locate the transponders relative to surveyed benchmarks this source of error will be minimized. The second largest contributor, slant range, can be reduced by site selection, distance selection or increased computational power.

C. PROGRAMS

1. The only programmable calculator available to the author was the Hewlett-Packard HP-65. It has a limited number of program steps (100) and a limited number of storage registers (8), because of trigonometric functions.

2. The display desired gives the position of the helicopter in polar coordinates from the transmitting antenna, all on one display line. The distance is presented in kilometers and thousandths (1 meter resolution) and the azimuth in degrees, with a rounding error of 0 to -0.999-- degree.

3. Using the law of cosine, the angle between the transponder baseline (D1 to D2) and the vector from D1 to the helicopter is calculated. This angle is added to the baseline azimuth to produce the true azimuth of D1 to the helicopter. The true distance has been measured by the DMU as D1. The clockwise (CW) and counterclockwise (CCW) solutions refer to the position of the helicopter, with respect to the baseline, as viewed from D1.

4. The helicopter vector is added to the vector from the transmitting antenna to transponder D1.

5. The resultant vector gives the helicopter position.

6. This program runs in approximately 7 seconds which is sufficiently fast for on-board navigation. Other, more elaborate programs to correct for slant range errors, will probably run longer.

7. An additional feature that could be added, using a more powerful computer, would be for corrective navigation instructions to the pilot during the travel to a measurement site. The courses should be done in degrees magnetic to simplify the pilot's work.

8. Programmable calculators such as the HP-67 and HP-41C would have the capacity to do slant range and course correction.

9. The range data program is shown in tables G1 and G2.

10. The position solution program is shown in tables G3 and G4.

TABLE G-1.

HP-65 User Instructions

Title Position by DME - Range Parameters Page 1 of 2

Programmer J. C. HANSELMAN Date 20 Apr 1979

Range Parameters - Format
LOAD RCL 1 RCL 2 RCL 3 RCL 4

STEP	INSTRUCTIONS	INPUT DATA/UNITS	KEYS		OUTPUT DATA/UNITS
1	ENTER FORMAT CARD				
2	INITIALIZE POINTER		RTN		
3	SWITCH TO W/PRGM				
4	ENTER PROGRAM FOR LBL A AS SHOWN ON THE		LBL		
	REVERSE SIDE, ENDING WITH RTN.		A		
			etc.		
5	RECORD ON SIDE 2 OF A "POSITION BY DME" CARD		RTN		
	AND PROTECT. (TO TEMPORARILY STORE THE				
	COMPLETED PROGRAM, RECORD ON SIDE 2 OF THIS				
	CARD - UNPROTECTED)				
6	DO NOT KEY IN LBL's B, C, D, OR E. THEY				
	WERE ON THE FORMAT PROGRAM PREVIOUSLY ENTERED.				

TABLE G-2.

HP-65 Program Form

Title Position by DME - Range Parameters Page 2 of 2

SWITCH TO W/PRGM PRESS f PRGM TO CLEAR MEMORY

KEY ENTRY	CODE SHOWN	X	Y	Z	T	KEY ENTRY	CODE SHOWN	X	Y	Z	T
LBL	23					m					
A	11					m					
D						m					
.	83					m					
d						m					
d						m					
d						m					
d						m					
d						EEX	43				
d						N					
d						N					
d						STO 4	33 04				
d						f	31				
EEX	43					STK	42				
N						DSP	21				
N						9	09				
STO 1	33 01					RTN	24				
M						LBL	23				
.	83					B	12				
m						RCL 1	34 01				
m						R/S	84				
m						f	31				
m						STK	42				
m						RTN	24				
m						LBL	23				
m						C	13				
m						RCL 2	34 02				
m						R/S	84				
EEX	43					f	31				
N						STK	42				
N						RTN	24				
STO 2	33 02					LBL	23				
D						D	14				
.	83					RCL 3	34 03				
d						R/S	84				
d						f	31				
d						STK	42				
d						RTN	24				
d						LBL	23				
d						E	15				
d						RCL 4	34 04				
d						R/S	84				
d						f	31				
EEX	43					STK	42				
N						RTN	24				
N											
STO 3	33 03										
M											
.	83										
m											

TO RECORD PROGRAM INSERT MAGNETIC CARD WITH SWITCH SET AT W/PRGM

REGISTERS

- R_1 TR1→TR2 Baseline Az. (°T)
- R_2 TR1→TR2 Baseline Length (m)
- R_3 STA→TR1 Azimuth (°T)
- R_4 STA→TR1 Distance (m)
- R_5
- R_6
- R_7
- R_8
- R_9

LABELS

- A LOAD
- B RCL 1
- C RCL 2
- D RCL 3
- E RCL 4
- 0
- 1
- 2
- 3
- 4
- 5
- 6
- 7
- 8
- 9

FLAGS

- 1
- 2

TABLE G-3.

HP-65 User Instructions

Title: Position by DME, Distance and Azimuth from Station — Page 1 of 2

Programmer: J. C. HANSELMAN — Date: 4 January 1979

Position by DME CW CCW (Program 2) | SPARE PROGRAM

STEP	INSTRUCTIONS	INPUT DATA/UNITS	KEYS		OUTPUT DATA/UNITS
1	ENTER: RANGE PARAMETER PROGRAM CARD (SIDE 2)				
2	STORE RANGE PARAMETERS		A		
3	ENTER: POSITION BY DME PROGRAM CARD (SIDE 1)				
4	KEY IN: DMU 1	Meters	ENT		
	DMU 2	Meters			
5	EXECUTE IF VEHICLE IS CLOCKWISE (RIGHT)		A		
	OF BASELINE				
6	EXECUTE IF VEHICLE IS COUNTERCLOCKWISE (LEFT)		B		
	OF BASELINE				

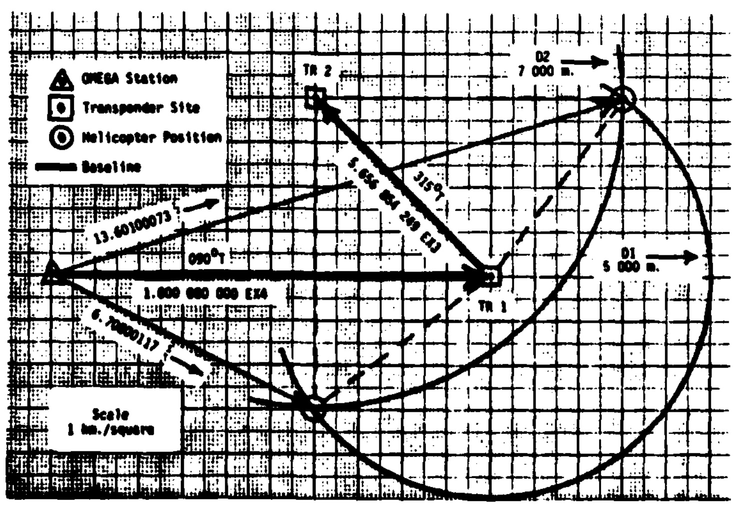

TABLE G-4.

HP-65 Program Form

Title Position by DME, Distance and Azimuth from Station Page 2 of 2

SWITCH TO W/PRGM PRESS f PRGM TO CLEAR MEMORY

KEY IN: DMU 1 (Meters)

PRESS : ENTER↑

KEY IN: DMU 2 (Meters)

KEY ENTRY	CODE SHOWN	X	Y	Z	T
LBL	23				
A	11				
D	14				
RCL 1	34 01				
+	61				
3	03				
6	06				
0	00				
g x≤y	35 22				
-	51				
g x⇄y	35 07				
g x⇄y	35 07				
STO 5	33 05				
E	15				
RTN	24				
LBL	23				
B	12				
D	14				
RCL 1	34 01				
g x⇄y	35 07				
-	51				
0	00				
g x>y	35 24				
3	03				
6	06				
0	00				
+	61				
+	61				
STO 5	33 05				
E	15				
RTN	24				
LBL	23				
D	14				
STO 8	33 08				
g R↓	35 08				
STO 6	33 06				
RCL 2	34 02				
f-1	32				
√x	09				
RCL 6	34 06				
f-1	32				
√x	09				
+	61				
RCL 8	34 08				
f-1	32				
√x	09				
-	51				
2	02				
÷	81				
RCL 2	34 02				

KEY ENTRY	CODE SHOWN	X	Y	Z	T
RCL 6	34 06				
X	71				
÷	81				
f-1	32				
COS	05				
RTN	24				
LBL	23				
E	15				
RCL 3	34 03				
RCL 4	34 04				
f-1	32				
R→P	01				
RCL 5	34 05				
RCL 6	34 06				
f-1	32				
R→P	01				
g x⇄y	35 07				
g R↑	35 09				
+	61				
g x⇄y	35 07				
g R↑	35 09				
+	61				
f	31				
R→P	01				
f	31				
INT	83				
EEX	43				
3	03				
÷	81				
g x⇄y	35 07				
0	00				
g x>y	35 24				
3	03				
6	06				
0	00				
+	61				
+	61				
EEX	43				
8	08				
÷	81				
+	61				
DSP	21				
.	83				
8	08				
RTN	24				

DISPLAY

M M . m m m 0 0 D D D

Distance (km) Azimuth (°T)

Station to Vehicle

REGISTERS	
R_1	TR1 → TR2 Baseline Az. (°T)
R_2	TR1 → TR2 Baseline Length (m)
R_3	STA → TR1 Az. (°T)
R_4	STA → TR1 Distance (m)
R_5	B1
R_6	b
R_7	Not Used
R_8	c
R_9	USED

LABELS	
A	CW
B	CCW
C	
D	Δ SOL.
E	+ VECTOR
0	
1	
2	
3	
4	
5	
6	
7	
8	
9	

FLAGS	
1	
2	

TO RECORD PROGRAM INSERT MAGNETIC CARD WITH SWITCH SET AT W/PRGM

11. A sample range and position diagram is shown as figure G-2. The range and position data is scaled directly from the grid or calculated using the Pythagorean Theorum with the exception of the azimuths of the two helicopter positions. These may be obtained by scale from the grid and use of trigonometry. This sample illustrates the precision of the program by independent calculation.

12. The notation "EX(N)" means the exponent of 10. This form is used because of the keyboard of the calculator used.

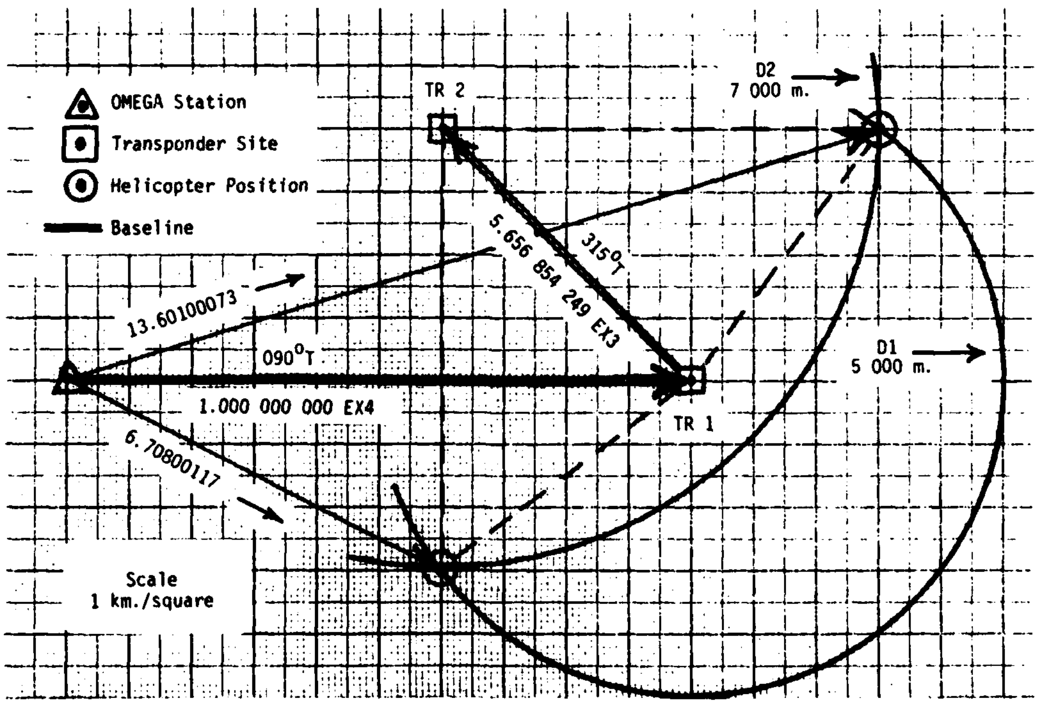

Figure G-2.

APPENDIX H. EQUIPMENT FOR FIELD INTENSITY MEASUREMENTS

Equipment furnished specifically for field intensity measurements.

The equipments listed in table H-1 below were delivered to OMEGA La REUNION for retention and use in conducting future field intensity measurements.

TABLE H-1.

Equipment	Mfgr	Model No.	Serial	Decal
Loop Antenna	Stoddart	90117-3	500286	1725
VLF Tuned Amplifier	Megatek	LPA-1A	500300	1854
Signal Generator	Hewlett Packard	204-D	05264	1746
Digital Volt-Ohm-Meter	Fluke	8600A-01	0585151	1754
Current Transformer	Pearson	1114-4	2283-4	1781
Oscilloscope	Tektronix	455	B044142	1765
Battery Power Supply	Tektronix	1106	B023372	1773
Tripod	Leitz	7563-20	None	None
Twinax Cable (50 ft)	-	RG-108/U	None	None
Coax Cable (50 ft)	-	RG-58/U	None	None
Ext. Attenuator for LPA-1A	Megatek	None	None	None